



MODIFICATION AND PERFORMANCE EVALUATION OF NSPRI SMOKING KILN

BY

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MASTERS DEGREE IN AGRICULTURAL AND ENVIRONMENTAL ENGINEERING
(PROCESSING AND STORAGE)**

AUGUST, 2019

DECLARATION

I hereby declare that this work is the product of my research efforts undertaken under the supervision of Dr. S. K. Shittu and has not been presented anywhere for the award of degree or certificate. All sources have been duly acknowledged.

.....
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CERTIFICATION

This is to certify that the research work for this dissertation and the subsequent write-up of this dissertation by BABAGANA IBRAHIM (SPS/14/MAE/00009) were carried out under my supervision.

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APPROVAL

This is to certify that this dissertation titled “Development of an improved fish smoker for medium scale processors” has been examined as adequate in scope and contents and approved for the award of Master Degree of Agricultural Engineering in (PROCESSING AND STORAGE) by the School of Postgraduate Studies through Department of Agricultural and Environmental Engineering, Bayero University Kano.

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DEDICATION

This dissertation is dedicated to Prophet Muhammad (S.A.W), his Household and his humble companions.

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TABLE OF CONTENTS

Title Page	ii
Declaration	iv
Certification	v
Approval	vi
Dedication	vii
Acknowledgment	viii
Table of content	x
List of Plate	xiii
List of Figure	xiv
List of Tables	xv
Abstract	xvi

CHAPTER ONE: INTRODUCTION

1.1	Background of the Study	1
1.2	Statement of the Problem	2
1.3	Objectives of the Study	4
1.4	Justification	4
1.5	Scope and Limitations	5

CHAPTER TWO: LITERATURE REVIEW

2.1	Overview of Global Fish Production	6
2.2	Fish Preservation	7
2.3	Methods of Fish Preservation	7
2.3.1	Traditional Method	8

2.3.2	Modern Method of Fish Preservation	11
2.3.3	Methods of Fish Drying	13
2.4	Review of some Literatures on Fish Smoking Ovens	17
2.5	Problems encountered by traditional fish smoking Ovens	20
2.6	Types of Traditional Ovens	21
2.7	Review of some Literatures on Fish Smoking Kilns	19
2.8	Component of Existing Smoking kiln	20
2.9	Drying Process	13
2.10	Thin-Layer Drying Equations:	14
CHAPTER THREE: MATERIALS AND METHODS		
3.1	Components of the Existing Smoking Kiln that were Modified	27
3.2	Modification of the Existing Fish Smoker	27
3.3	Re-Design Considerations	27
3.4	Design Parameter	28
3.4.1	Batch capacity	28
3.4.2	Amount of moisture to be removed	29
3.4.3	Smoking Rate	29
3.4.4	Mass of air required to Effect drying	29
3.4.5	Volumetric flow rate of the drying air	30
3.4.6	Design and selection of size and type of Blower to Convey the Drying Air	30
3.4.7	Heat required for drying	31
3.4.8.	Determination of quantity of charcoal needed for combustion	32
3.4.9	Solar System Selection	32
3.4.10	Thermal Resistance due Lagging R_{value}	33

3.4.11 Smoking Chamber	34
3.4.12 Smoking Tray	35
3.4.13 Heat Chamber	36
3.4.15 Oil Collector	37
3.5 Material Selection	38
3.6 Production Cost	39
3.7 Description of Modified smoking Kiln	40
3.8 Performance Evaluation of the Smoking Kiln	42
3.8.1 Performance Indicators	42
3.8.2 Choice of Experimental Factors	43
3.8.3 Sample Preparation	46
3.8.4 Experimental Procedures	47
3.8.5 Experimental Design and Layout	46
3.8.6 Analysis of the Data	48
CHAPTER FOUR: RESULTS AND DISCUSSION	
4.1 Smoking Efficiency	49
4.2 Smoking Rate	51
4.3 Output Capacity of the Modified Fish Smoker Using Different Heat Source.	53
4.4 Fuel Consumption	55
CHAPTER FIVE: SUMMARY, CONCLUSIONS AND RECOMMENDATIONS	
5.1 Summary	55
5.2 Conclusions	56
5.3 Recommendations	56
References	58
Appendces	66

LIST OF PLATE

PLATE 1: Front View of the existing NSPRI Fish Smoker	25
PLATE 2: Rear View of the existing NSPRI Fish Smoker	26
Plate 3.1 Side view of the Improved Fish Smoker	42
Plate 3.2: Cat fish <i>Clarias gariepinus</i>	47
Plate 3.3: Improved Fish Smoker in Operation	48

LIST OF FIGURE

Figure 3.1 Solar Sizer Xcel, Version 1.9

34

LIST OF TABLES

Table 2.1: Mathematical drying models	16
Table 3.1: Materials used for the Main Components of the fish smoker	39
Table 3.2: Machine Production Cost	40
Table 3.3: Experimental Layout for Performance Evaluation	45
Table 3.4 Outline of the Analysis of Variance for a 3 x 3 x 3 Factorial Experiments.	46
Table 4.1: Analysis of Variance for Smoking Efficiency	50
Table 4.2: LSD for Smoking (SE) for the Main Effects	51
Table 4.3: Analysis of Variance for Smoking Rate	52
Table 4.4: LSD for Drying Rate (DR) for the Main Effects	53
Table 4.5: Output capacity of the developed fish smoker with different heat sources	53
Table 4.6: Fuel consumption of the developed fish smoker with different heat sources	54

ABSTRACT

The most widely employed traditional methods of processing and preserving fish for human consumption in Nigeria are smoking and drying. However, the traditional smoking and drying methods are associated with poor quality of the products, low capacity, longer processing time and poor energy efficiency. This study is aimed at modification of an existing smoking kiln for better performance. Components of the existing smoking kiln that were modified are; Non-rechargeable batteries were replaced with solar rechargeable batteries, Capacity of the smoking kiln was upgraded by increasing the number of trays, smoking kiln was lagged to conserve heat for efficient smoking. The smoking kiln consists of four major units. These include: fish smoking chamber, heat chamber, oil collection unit and heat circulation unit. The smoking chamber consist of six trays and air circulating fan. The oil collection unit consists of an open tray placed below the six fish trays. The solar panel charges the battery which operate the fans. The smoking kiln has a batch capacity of processing 60 kg live weight (average initial moisture of 72 % wb) of cat fish. Performance evaluation of the modified smoking kiln was carried out using a Completely Randomized Design (CRD) in a 3x3x3 factorial experiment. The smoking kiln was evaluated using Output capacity (kg/h), smoking rate (kg/h), smoking efficiency (%) and fuel consumption rate (kg/h) as performance indicators and Tray position, T,(Upper, T1, Middle, T2 and Lower, T3.) Fuel source, C (Charcoal, C1, Sawdust, C2 and rice husk, C3 (kg)) and Fan speed, S (S1 = 400 rpm, S2= 600 rpm and S3= 800 rpm) as independent variables. Results revealed that independent variables and their interactions were found to be of great influence to performance indicators. The best combination of variables which give the highest smoking efficiency (64.06 %) is at speed of S₃ (800 rpm) and charcoal (C₁). The best combination which gives highest smoking rate (58.59 Kg/h) is the one using either charcoal (C1) or sawdust (C2) at a speed of S₁(400 rpm). The best combination which gives the highest mean values of output capacity (93.94 Kg/h) is the one with a speed (S₃) of 800 rpm using Charcoal as heat source at tray position T₁. Comparing the results of the modified fish smoker and that of the existing smoker, under the same conditions modified smoker has 159 % and 35 % increase in output capacity and smoking efficiency respectively.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Fish is a vertebrate animal, living in fresh and seawater. It is one of the main sources of animal protein foods available for human consumption (Abdullahi, 2000). Most of the catch comes from oceans, seas, rivers and lately from man-made ponds. It is a highly nutritious food of about 50-55% water, 12-19% protein, 10-15% fat, 10% mineral and 1% carbohydrate (Adams and Moss, 1999). It is often cheaper than meat and so it is a rich protein source for both the poor and the wealthy.

Fish is one of the most perishable of all staple commodities (Ikutegbe and Sikoki, 2014). They are suitable media for the growth and proliferation of microorganisms (Ghaly *et al.*, 2010). Losses of fishes arising from bacterial and autolytic spoilage are up to 20% (Uzukegbu and Eke, 2000). Hence preservation of fresh fish becomes very important. This can be achieved by freezing; canning, dehydration through smoking and drying, etc. Currently, smoking is the main method of fish preservation in the rural areas of Nigeria. According to FAO (2007), smoking is one of the preservative methods employed by traditional fishermen to preserve fish using traditional kilns of various types depending on the locality.

Smoking is a traditional preservation technique used in preserving fish for long storage. Smoke contains substances that kill bacteria, thus helping to preserve the product, while the heat dries the fish (Ashaolu, 2014). In tropical countries, fish are generally smoked at relative high temperature so that they are smoked and dehydrated (Eyo, 2001).

The basic essence of smoking is to reduce the moisture content of the product to a level that prevents deterioration within a certain period of time normally regarded as the “safe period”(Ogunleye and Awogemi, 2008).

Clucas, (1982) stated that at moisture content of 15% or less mould will cease to grow on the fish and well dried fish if stored under right conditions can be kept for several months.

1.2 STATEMENT OF THE PROBLEMS

Storage of fresh fish without preservative or poor processing measures make it to be highly susceptible to deterioration (Okonta and Ekelemu, 2005). Due to its chemical composition, fish is a perishable food material and its flavour and texture changes rapidly during storage after death. In many rural fishing communities, the infrastructures for post-harvest processing and preservation of fish are inadequate as a result losses up to 30% of the total catch by weight have been reported (Ghaly *et al.*, 2010). Amos, (2007) also reported that the fishing industry despite its importance suffers from enormous post-harvest losses which are estimated at 35-40% of total weight. FAO, (2001) estimated that post-harvest losses remain about 25% of the total world catch annually. These losses have a profound adverse impact on fishing communities whose status and income often depend on fishing activities. Report revealed that small scale farmers in different part of the world account for about 50 to 70 percent of the national fish farming in most countries and 30 to 40 percent of these fishes are usually lost due to poor handling and inadequate processing (Ologunagba *et al*, 2010).

Hence preservation of fresh fish becomes very important. Though, there are modern fish preservation techniques such as drying, canning, use of additives, pasteurization, freezing and refrigeration, most of these techniques are expensive and unaffordable to rural farmers and

processors who are mostly small scale processors. Therefore, smoking of fish still remain predominant in most communities where fish processing is carried out in Nigeria (Davies and Davies, 2009; Ologunagba *et al.*, 2010).

In Nigeria fish smoking practices are yet to gain prominence on a large commercial scale due to lack of appropriate technologies to assist the fish farming business (Ashaolu, 2014). Many studies revealed that medium scale processors and fish farmers in Nigeria are still using traditional method of fish smoking which has long processing duration and low capacity resulting in low quantity of fish processed (Abolagba and Nunta, 2011).

The fish smoking kiln developed in response to this realization were found to have low efficiency and some limitations. For instance, preliminary study of the fish smoking kiln developed at Nigerian Stored Product Research Institute (NSPRI) Kano, revealed the following limitations

- i. Low smoking rate resulting in low capacity of the smoking kiln (40 kg per batch).
- ii. Excessive heat loss thereby reducing the thermal efficiency of the smoking kiln (smoking kiln not lagged)
- iii. High running cost.

1.3 OBJECTIVES OF THE STUDY

The main objective of the study is to develop an improved fish smoker.

The specific objectives are:

- i. To Carry out design modification of NSPRI smoking kiln
- ii. To Construct the modified smoking kiln, and
- iii. To Evaluate the performance of the fish smoking kiln.

1.4 JUSTIFICATION

The relevance of fish as food has been recognized by man in time past. Fish is rich in protein and minerals like calcium, phosphorous and iron (Ologunlagba *et al.*, 2010). It is an important component of the diet of most people, as fish is a major source of protein for man and animal. Fish smoking prolongs shelf life, enhances flavour and increases utilization in soups and sauces (FAO, 2007). It reduces waste at times of bumper catches and permits storage for the lean season (Eyo, 2001). It increases protein availability to people throughout the year and makes fish easier to pack; transport and market (Ologunlagba *et al.*, 2010). The demand for fish is on the increase both at local and global markets. Large scale processing of fish is necessary to satisfy the growing demand (Davies and Davies, 2009). Thus the development of a more efficient smoking kiln would contribute immensely to fish processing activities. Through the intended modification, the new smoking kiln will be of higher capacity, cost effective and more efficient. In addition, the smoking kiln will reduce the dependency on imported ones to Nigeria and as well be used by the farmers and unemployed youth as a business venture which in turn will reduce unemployment rate and improve the standard of living of the people.

1.5 SCOPE AND LIMITATIONS

The study will be limited to modifying an existing NSPRI smoking kiln. Size of the kiln was changed but its capacity and efficiency was improved.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW OF GLOBAL FISH PRODUCTION

Global aquaculture production reached 106 million tonnes, in 2015, with 76.6 million tonnes of aquatic animals growing at an average annual rate of 6.6 percent since 1995. This positive trend, although now slowing, is projected to continue; consequently, the aquaculture sector is expected to play a greater role in contributing to food security, poverty alleviation and economic development of the poor. However, the global population is increasing and, in order to maintain at least the level of per-capital consumption of 19.7kg aquatic foods as of 2013, according to FAO, (2016), the world will require an additional 23 million tonnes thereof by 2020. This additional supply will have to come from aquaculture.

In the world, during the period 1995-2015, production from feed-dependent aquaculture increased over fourfold from 12.2 to 50.7 million tonnes, largely through intensification of production methods. The use of aquatic species/species groups such as tilapias, carps, shrimp and salmonids with established aquaculture technologies provided firm market opportunities for increasing production and driving production efficiency.

In Nigeria, fish production through aquaculture has risen steadily from a few hundred kilograms in the 1950s to over 45,000 metric tonnes in 2004 (FAO, 2016). Aquaculture is the fastest growing livestock production sector in Nigeria, with a growth of about 29% in 2006 alone and with prospects of continued growth. FAO, (2016), stated that demand for fish is increasing with population growth, while catches from fisheries are declining, even globally.

2.2 FISH PRESERVATION

Preservation is the action of protecting foods so that they can be stored longer (Ali, 2014). Man is dependent on products of plant and animal origin for food. Most of these products are readily available only during certain seasons of the year, fresh food spoils quickly, and therefore, many methods have been developed to preserve these foods

.Fish preservation according to FAO (2001) is an important aspect of the fisheries (FAO, 2001). FAO, (2007), stated that, fish farms or other fish capturing sites are located far off from the market place and there is chance of fish decomposition and the uncertainties of their sale in market, hence effective fish preservation techniques is imperative. When the fishes are caught in numbers greater than the amount of consumption, their preservation becomes a necessity for their future use (Abah, 2002). Preservation and processing therefore become a very important part of commercial fisheries. Preservation is done in such a manner that the fishes remain fresh for a long time, with a minimum loss of flavour, taste, odour, nutritive value and the digestibility of their flesh (FAO, 2007).

2.3 METHODS OF FISH PRESERVATION

In most developed countries, canning or freezing methods are used for fish preservation to improve the shelf life (FAO, 2001). However, in underdeveloped and developing countries, traditional methods are still practiced, because of erratic power supply and high costs of the equipment (Adamu *et al.*, 2013).

2.3.1 Traditional Methods

Traditional methods of fish preservation are probably the oldest methods used for preserving fish in the developing countries because they are simple and cheap methods. Akinola *et al.* (2006) reported that despite the rudimentary nature of traditional methods, lack of control over the drying rate, (sometimes results in under-drying or over-drying), exposure to unexpected winds, dust, dirt, insect infestation and contaminants such as flies, the methods still remain predominant in Nigeria. These preservation methods include salting, frying, drying and smoking

a) Salting

Salting is one of the most common pretreatments used for the fish products (FAO, 2001). Salting converts fresh fish into shelf-stable products by reducing the moisture content, and acting as a preservative (Rahman, 2006). Fish are salted over the temperature range of 0–38⁰C. The higher the temperature, the faster the salt infusion, and quicker the process reaches equilibrium (Rahman, 2006). The osmotic dehydration process (salting) can be characterized by equilibrium and dynamic periods (Ali, 2014)

b) Frying

Frying is defined as a process of cooking and drying through contact with hot oil (Oreopoulou *et al.*, 2006). Objective of frying is to make the food to be more palatable and tasteful. Also, by frying, the food is safer and it provides a preservative effect that result from thermal destruction of microorganisms and enzymes. Frying reduce food water activity thereby increase food shelf life. Fishes that are smoked have a shelf life up to several months, which is mostly limited by quality deterioration of the absorbed oil and development of a rancid odour and flavour (Oreopoulou *et al.*, 2006). Fish can be preserved by frying in oil. The oil helps to cook and dry

the fish to protect the surfaces from attack by spoilage organisms and also helps to reduce moisture content of the fish thereby preserving the fish.

c) Drying

Drying is an ancient phenomenon that existed from the ancient times, but the technological research work into the concept of drying process started around mid-twentieth century (Eyo, 1997). Drying process play a very important role in the preservation of fish (Ali, 2014). It is an excellent way to preserve food, which was probably the first ever food preserving method used by man, even before cooking (Alamu *et al.*, 2010). It involves the removal of moisture from agricultural produce so as to provide a product that can be safely stored for longer periods of time.

Drying is a simultaneous heat and mass transfer process consisting of the removal of water in moisture form, by evaporation from the surface of a substance under consideration. There are two stages in the fish drying process (Eyo, 1997):

- i. Removing the surface moisture, and
- ii. Removing the internal moisture within the fish.

The drying rate in the first stage depends on ability of air passing over the fish to absorb or remove moisture. This depends on the air speed and Relative Humidity (RH). High outside temperature and increased surface area of the fish (by opening it up), hastens the drying process. The duration of the second drying stage is determined by the rate at which moisture can migrate through the tissue to the surface of the fish. The rate of movement of water within the fish depends on factors such as (Eyo, 1997):

- i. Fat content of the fish Fat acts as a barrier to water movement and slows down the drying rate

- ii. Thickness of the fish (The thinner the fish the faster the drying rate)
- iii. Moisture content (Movement of the water to the surface becomes more difficult when the fish becomes dry and the fat content becomes higher).

If during the early drying stage the fish is dried at high temperature (more than 40 °C) or when the relative humidity is too low, the outer layers become harden and hinder internal moisture movement to the surface. This effect is known as 'case hardening' (Eyo, 1997). The fish may appear dried but water becomes trapped inside leading to insufficient drying and early spoilage.

d) Smoking

Smoking is a traditional method of preserving fish commonly use in Nigeria (Eyo, 1993). Smoking of fish is one of the most ancient and important preserving processes (FAO, 2007). Smoking is a slow process and it is not easy to control the process. Fish smoking virtually does three things: it dries, kill existing germs and add flavor to the fish. Traditionally, fish smoking is done by making fire in a mud oven or in a container. Wire gauze is placed on top of the oven and fish to be smoked are placed on top of the wire gauze. To prevent burning, fish is turned frequently during smoking. The smoke from the fire help to enhance the flavour of the produce and inhibit bacterial growth on the surface of the product (Ashaolu, 2014).

Smoke contains phenolic compounds, acids, and carbonyls and smoke flavour is primarily due to the volatile phenolic compound (Abdullahi, 2000).

The smoking methods of fish preservation typically produce high salt and low moisture content products that are not desirable to most modern consumers (Ali, 2014).

Advantages of traditional methods

They are the simplest and cheapest methods of preserving fish (Tawari, 2006). Most of the equipments are cheap and can be assembled using locally available materials. Easy to use, with large capacity, low firewood consumption and shorter smoking times and reasonable nutritional value.

Disadvantages of traditional methods

Disadvantages of these methods include lack of influence over the process and the finished product with consequent health concerns if the fish is not properly dried. Traditional fish smoking kilns are poorly constructed and lack mechanisms for the control of smoke and heat production, all of which affect the efficiency of smoking and the quality of the final products. The smoking procedure is very laborious and poor quality smoked fish of low market value are produced.

2.3.2 Modern methods of fish preservation

The modern methods of preserving fish are more complicated compared with the traditional methods. These modern fish preservation techniques include drying, canning, use of additives, pasteurization, freezing and refrigeration (Ologunagba *et al.*, 2010).

Refrigeration/cold storage : the fishes are kept at temperatures lower than that of the room temperature in refrigerators. The temperature in the refrigerators will not allow the spoilage organisms to grow and the fishes are preserved.

Freezing : fishes are stored at a temperature below 0 °C. This completely hinders the activities of micro organisms and the fishes are preserved for a long time. It should be noted that freezing does not kill most micro organisms. Therefore, if frozen fish is brought back to warmer

temperatures, the micro organisms become active again thereby resulting in fish spoilage. Freezing for too long also cause chilling injury.

Canning :This is a process of storing fish products in hygienically sealed containers (FAO, 2007). The containers are washed and sterilized by heating them in boiling water (at a temperature of 100 0C). The product is then heated to temperature high enough to destroy all micro organisms.

Advantages of modern methods of fish preservation

Modern preservation constitutes a very important aspect of the fish industry. Ability to preserve large amount of fish and for a longer period of time. Preservation must be seen as a way of storing excess fish that are abundantly available at certain times of the year, so that they can be consumed in times when fish is scarce. Consumption of fresh fish is always preferable. In times of scarcity, preserved fish can be a welcome addition to the diet. Modern preservation method have larger capacity, very effective and ability to maintain higher nutritional value.

Disadvantages of modern methods of fish preservation

Although the preservation and processing constitute a very important aspect of the fish industry, it has certain drawbacks, as well, particularly with respect to electricity, is fast becoming a less reliable source of energy for fish processing and preservation (Eyo, 1997) .

2.3.3 Methods of fish drying

Drying is an ancient phenomenon that existed from the earth's creation, but the technological research work into the concept of drying process started around mid-twentieth century (Eyo, 1997). Drying process play a very important role in the preservation of fish (Ali, 2014).

Drying is a process of moisture removal from a product whereby the moisture content of the product is reduced to a predetermined value, usually by movement of heated air through the product.

2.4 DRYING PROCESS

Drying is a process of simultaneous heat and mass transfer (Michael, 1991) . It involves two fundamentals physical processes: the transfer of heat to evaporate moisture and the transfer of mass or moisture within and from the drying product. The heat transfer may be in form of conduction, convection or radiation while the mass transfer may be in form of liquid as it diffuses to the surface and/or as a gas diffusing outward from the product (Zakari, 2000).

Drying, in thin layer, is one in which individual product are fully exposed to the drying air (Henderson *et al.*, 1997). In this operation, the actual rate of moisture removal is not constant throughout the drying process but declines as the moisture content decreases. Henderson *et. al.* (1997) describe the drying period as follows:

- i. The constant rate drying period, and
 - ii. The falling rate drying period.
- i. Constant rate drying period

In the constant rate drying period, drying is characterized by constant rate of water loss. During this period, evaporation occurs at the surface of the product and is similar to evaporation from a

free water surface. The rate of drying is determined by amount of water present and the surrounding conditions. In this drying segment, the energy required may be provide by radiation, conduction or convection.

ii. Falling rate drying period

When all the moisture at the surface of the material has been exhausted, moisture is diffused from the internal part of the product. This segment is known as falling rate period. Drying in the falling rate period involves two processes. These include the movement of moisture within the material to the surface and the removal of the moisture from the surface.

2.5 THIN-LAYER DRYING EQUATIONS

Thin layer drying models (moisture ratio equations) that describe the drying phenomenon of agricultural materials mainly fall into three categories, namely theoretical, semi theoretical and empirical (Parti, 1993; Abdallah and Amri, 1999). The first takes into account only internal resistance to moisture transfer while the other two consider only external resistance to moisture transfer between product and air (Akpınar *et al.*, 2006). Similarly, Guan, *et al.*, (2013) categorized thin-layer drying models as theoretical, semitheoretical and empirical models.

The semi-theoretical model based on the theory and the drying kinetics experimental, is derived from the simplification of Fick's second law of diffusion or modification of the simplified model, which has been widely used to describe the drying characteristics. Semi-theoretical models offer a compromise between theory and ease of use; they require small time compared to theoretical thin layer models and do not need assumptions of geometry of a typical food, its mass diffusivity and conductivity (Ozdemir, and Devres, 1999).

Among semi-theoretical thin layer drying models, the Newton (Lewis) model, Page model, the modified Page model, the Henderson and Pabis model, the logarithmic model, the two-term model, the two-term exponential, the diffusion approach model, the modified Henderson and Pabis model, the Verma model and the Midilli–Kucuk model are used widely (Akpinar *et al.*, 2006).

Empirical models derive a direct relationship between average moisture content and drying time (Ismail, and Ibn Idriss, 2013). They neglect fundamentals of the drying process and their parameters have no physical meaning. Therefore they cannot give a clear accurate view of the important processes occurring during drying although they may describe the drying curve for the conditions of the experiment. Among them, the Thompson model and the Wang and Singh model have been found application in the literature.

According to (Meisami-asl *et al.*, 2010) theoretical models could be used for different materials and conditions, but contain diffusion or heat and mass transfer equations, and thus, the usability of these models decreases; semi-theoretical models contain parameters directly related to material properties and the empirical equations give a satisfactory fit to all the experimental data and take less computing time in comparison to the theoretical equations.

Chen and Jayas (1998) reported that thin- layer drying equations of the form of Equation 1 have contributed to the understanding of heat and mass transfer phenomena for designing and improving of drying equipment. This equation can be represented as:

$$MR = \frac{M_t - M_e}{M_o - M_e} = F(t) \quad (1)$$

Where,

MR = Moisture ratio

Mt = Moisture content at time, t (%db)

M_o = initial moisture content (%db)

M_e = equilibrium moisture content (%db)

$F(t)$ = a function of drying time.

Table 2. 1: Mathematical drying models

MODEL NAME	MODEL
Lewis	$MR = \exp(-kt)$
Henderson and Pabis	$MR = a \exp(-kt)$
Page	$MR = \exp(-ktn)$
Wang and Singh	$MR = 1 + bt + at^2$
Logarithmic	$MR = a \exp(-kt) + b$
Midilli	$MR = a \exp(-ktn) + bt$

Where, k is the drying constant and a , b , n are equation constants. (Darvishi *et al.*, 2012)

2.6 REVIEW OF SOME LITERATURES ON SMOKING OVENS

Fish smoking in Ghana is traditionally carried out by women in coastal towns and villages, along river banks and on the shores of Lake Volta. In most fishing communities, in fact, the main economic activity of women is fish processing. Depending on the type of fish to be smoked, its uses and possible storage period, the smoking process can take the form of “wet” hot smoking or “dry” hot smoking. Both processes are carried out at temperatures above 80°C, which are high enough to cook the fish. (Eyo, 2001).

Until the end of the 1960s, the ovens most used for smoking fish in Ghana were cylindrical or rectangular and made of mud or metal. Using these ovens had considerable disadvantages, however, such as excessive handling of fish during smoking, a problem more severe when smoking small species of fish such as anchovies. The ovens had a low capacity, were inefficient in fuel usage and could not cope with the large volumes of fresh fish landed during bumper fish seasons. This contributed to high post-harvest losses and, since the fish season also coincided with the rainy season, the fish could not be sun-dried. Because traditional ovens were inefficient, more firewood than necessary was used for the smoking process, which contributed to forest depletion. Health of the women fish smokers was at risk, because the smoke entered their eyes and lungs, they burned their fingers and they were exposed to direct heat. The fish smoking procedure was very laborious and poor-quality smoked fish was produced. (FAO, 2016)

In the early 1950s, awareness of the shortcomings of traditional ovens had stimulated development work on new and improved smoking ovens, such as the Adjetey, Altona, Ivory Coast and Nyegesi models. For various reasons, however, none of these was accepted when introduced in Ghana. (FAO, 2007)

In the light of lessons learned from the constraints and disadvantages associated with these earlier ovens, an improved traditional fish smoking oven, the Chorkor, was developed and introduced in 1969. This innovative model, developed by the Food and Agriculture Organization of the United Nations (FAO) and the Food Research Institute of the Council of Scientific and Industrial Research (CSIR) in Ghana, has since demonstrated the potential of traditional technologies in meeting current challenges.

The Chorkor oven, named after a small fishing hamlet on the outskirts of Accra, has numerous advantages. It is cheap to make and can be assembled using locally available materials. Easy to use, with large capacity, low firewood consumption and shorter smoking times, it produces high-quality smoked fish. This simple, highly effective fish smoking technology was popularized in Ghana through a number of training programmes and promoted using the participatory approach. Fish processors were involved from the outset in the implementation process, thus ensuring high acceptance and adoption rates. In each community, fish smokers were informed of the benefits of the Chorkor smoker and ten of them engaged in year-long fish smoking were chosen in each community. At least one mason and one carpenter were trained in each community to be responsible for the construction of additional ovens. As part of extension activities, a user manual was produced in English and French and a video cassette with an explanation of construction and use was produced for fish smokers, extension agents and students

The innovation of the Chorkor oven has led to enhanced incomes, living standards and nutritional status in fishing communities in Ghana. Its success has encouraged younger women to take up fish smoking as a profession and led to integrated programmes resulting in further socio-economic and community development in rural areas. Although initially developed for use in

Ghana, the Chorkor oven has now received wide acceptance in most western, central and eastern African countries through a number of initiatives supported by multilateral and bilateral sources. To date, Cameroon, Ethiopia, the Gambia, Kenya, Lesotho, Nigeria, Sierra Leone, Tanzania (including Zanzibar), Uganda and Zambia have demonstrated enthusiasm for and commitment to adopting this simple and cost-effective technology. The user-friendly and environmentally safe Chorkor oven holds valuable lessons for countries from other regions in the developing world.

2.7 REVIEW OF SOME LITERATURE ON FISH SMOKING KILNS

Fish processing through hot smoking or Kiln is an age long practice in most parts of the world (Ashaolu, 2014). Nigeria fish smoking practices are yet to gain prominence on a large commercial scale due to lack of appropriate technology to assist the fish farming business (Ashaolu, 2014). The need to mechanize fish processing techniques has drawn the attention of National Agricultural Research to devote interest and minimize the drudgery, reduce labour operation, and unsanitary and inherent unhygienic handling that are mostly involved in the traditional methods (Eyo, 2001).

In an effort to develop an effective method of fish smoking, different models of improved ovens and kilns were developed in various parts of Africa (Davies and Davies, 2009). Until the end of 1960, the oven most used for smoking fish was cylindrical or rectangular and made of mud or metal (Olayemi *et al.*, 2013). These ovens had considerable disadvantages. The disadvantages are low capacity, inefficient fuel usage (firewood) thereby contributing more to forest depletion and the health hazard which its operation entails as a result of the smoke which affects eyes and lungs of the operator. In addition, fingers are burnt due to undue exposure to direct heat, the procedure is very laborious and poor quality smoked fish are usually produced (Abolagba, and Nunta, 2011). These associated problems have not only limited fish smoking to the rural fisher

folks but has also hindered the trade of smoke fish (especially exportations from African countries to Europe) due to mould attacks resulting from poorly smoked products (FAO, 2016).

Davies and Davies (2009) reported that the development of appropriate fishing machinery and techniques that employed effective production, handling, harvesting, processing and storage, cannot be over-emphasized especially in the age when aquacultural development is quickly gathering momentum in Nigeria.

The effects of smoke-drying temperatures and duration of drying in the quality of Nile tilapia (*Oreochromis niloticus*) has been investigated by Idah and Nwankwo (2013) using a modified drum kiln dryer. The study indicated that smoke drying temperature and time influences both nutritive and physical quality of fishes (protein and colour). Tilapia was best smoked at 60°C and 70°C for 10 hours. Improved smoking kilns were developed to address the problems inherent in all traditional smoking technologies –lengthy drying periods, low capacities, poor smoked fish quality and inefficient energy use. However, local and regional fish smoking kilns have continually rejected most of the improved kiln designs introduced by national and international agencies because the designs have failed to consider critical socio-economic and cultural factors. Akande and Adeyemi (2016) developed a detachable fish smoking kiln and carried out performance evaluation using fresh water catfish (*Clarias gariepinus*) with average live weight of 350 g ± 50 g per piece as test organism. Result showed that the kiln has a batch capacity for processing 50 kg live weight (average moisture content, 72 % w. b.) of *Clarias gariepinus* to smoked dried fish (average moisture content, 5.5 % w.b.) in 10 h when operated at 110 °C ± 10 °C.

2.8 PROBLEMS OF TRADITIONAL FISH SMOKING OVENS

In the 1960s and 1970s, several types of traditional ovens were used for fish smoking. They could not cope with the large volume of fish landed, however, because of their low capacity and

inefficient smoking process. This led to high post-harvest losses and use of more firewood than necessary, which contributed to forest depletion. The health of women fish smokers was also placed at risk as a result of the smoke entering their eyes and lungs, their fingers being burnt and exposure to direct heat. The smoking procedure was very laborious and poor quality smoked fish of low market value was produced. (FAO, 2016).

The way fish is arranged for smoking in traditional ovens, in layers one on top of the other, prevents efficient circulation of heat and smoke. The smoking has to be interrupted frequently to rearrange the layers to prevent charring of the fish. In cases where sticks are used to separate the layers, the sticks exert considerable pressure on the fish, often disfiguring the smoked product and reducing its market value. None of the ovens described below had devices for controlling temperature and smoke during the smoking process, which was done by adding or removing firewood as and when necessary. (Eyo, 2001).

2.9 TYPES OF TRADITIONAL OVENS

Cylindrical mud oven

As the name implies, this oven is round and made of mud. It is widely used in the central and western regions of the country, taking the name Fanti from the inhabitants of these regions. The oven exists in various sizes but typically it has an external diameter of about 132 cm, internal diameter of about 105 cm and a height of about 80 cm. A ledge is made in the wall at about 50 cm from the bottom of the oven, on which sticks can rest to support the layers of fish to be smoked. The layers of fish are separated by sticks. Pieces of wire mesh can also be used to hold the fish for smoking instead of the sticks. A 42-48 cm hole is cut at the bottom of the wall for feeding firewood into the oven. (Eyo, 1997).

Disadvantages associated with this oven are the excessive handling of fish during smoking due to frequent reshuffling and damage to the fish caused by the sticks used to separate the layers. This problem is more serious in the smoking of small species of fish such as anchovies (*Engraulis encrasicolus*) than in the smoking of larger species such as grouper (*Epinephelu* spp.). Other problems are the oven: wears out after one or two seasons, time-consuming and smoky to operate, fuel inefficient, produces an unevenly smoked product and limited capacity. (FAO, 2007).

Cylindrical metal oven

The oven is usually constructed by joining together two opened 44-gallon steel oil drums and cutting a stokehole at the base. The average diameter of the metal oven is about 115 cm, with a height of about 90 cm and a stokehole of approximately 40x40 cm. Iron rods are fitted about 60 cm above the base of the drum to serve as a support for the layers of fish. This oven has been used throughout Ghana as well as in some other African countries. It is light and portable but susceptible to rust and corrosion. It suffers from the same shortcomings as the cylindrical mud oven. In addition, since it is made of metal, it gives off considerable heat during the smoking process, to the discomfort of the processor. (FAO, 2007).

Rectangular mud oven

This oven is rectangular in shape and constructed from mud. Thick iron bars are placed across the top of the base to support the layers of fish to be smoked. A stokehole is cut along one of the longer sides of the oven. The fish are arranged on pieces of wire mesh and placed on the supporting iron rods. Where more than one layer of fish is smoked, the layers are separated by sticks. This oven was mostly used in the Greater Accra and Volta regions.

Disadvantages include: difficulty in handling the hot wire mesh loaded with fish during the smoking, low capacity, loss of heat and smoke through the stokehole and round the layers of fish resulting in inefficient fuel use, damage caused by the sticks separating the layers of fish, excessive handling of fish during smoking, pieces of fish falling into the fire, especially if the wire mesh is damaged, difficulty in controlling the heat. (FAO, 2016)

Rectangular/square metal oven

This oven is normally constructed from 44-gallon steel oil drums, which are opened and joined to give a rectangular or square shape. Wooden battens are sometimes used for reinforcement. Thick iron rods are placed on top of the base to support the fish arranged on pieces of wire mesh. A large stokehole is cut at the base of the side wall. The disadvantages of this oven are similar to those of the rectangular mud model. It also radiates a great deal of heat. (FAO, 2016).

In the early 1950s, recognition of the shortcomings of traditional ovens boosted work on the development of new and improved smoking ovens in Ghana and other African countries. These included the Adjetey, Altona, Ivory Coast and Nyegezi ovens. (Eyo, 1997).

Adjetey oven

The oven, developed by the Fisheries Department of Ghana in 1962, is constructed from heavy metal and has a combustion chamber/firebox located at the side of an enclosed smoking unit. A metal tube connects the two chambers. There is a chimney on top of the smoking unit. The fish are arranged on metal trays placed in the smoking unit. The oven was not accepted by women, because of its high cost and operational inconvenience and because the final smoked fish product is not as dry as that from traditional ovens. (Eyo, 2001).

Altona oven

The oven originated in the former Federal Republic of Germany and was introduced in the 1970s by the German Volunteer Service to fish smokers at Biriwa, a fishing community in the Central Region. The oven consists of combustion/ firing chamber constructed of burnt bricks, with a stokehole at the bottom of the front wall. The metal smoking unit, which is fixed by concrete on top of the combustion chamber, is enclosed and has a chimney. The fish are skewered through the eyes with metal rods and hung in the enclosed chamber for smoking. The skewering process removes the eyes of the fish, however, which is unacceptable to consumers. Disadvantages of the Altona oven included the high cost, which women could not afford, and the fact that hanging fish for smoking represented a departure from traditional smoking techniques to which processors were accustomed. Introduction of a modified version, known as the Altona-type oven, also proved unsuccessful. (Eyo, 1997).

Ivory Coast oven

This type of oven consists of a square wooden frame to which aluminum sheets are nailed to form the sides. The fire chamber is made from one-and-a-half 44- gallon oil drums joined together, with one end of the drums opened. A hole is cut out of the upper part to allow the smoke and heat to pass through to the fish loaded on trays. A perforated metal plate is suspended above the hole to serve as a spreader. Three trays made from wooden battens with pieces of wire mesh nailed across them are placed on top of the framework. Aluminum sheet is used to cover the entire structure to retain heat and smoke. The oven was introduced to Cote d'Ivoire and a number of other African countries but not Ghana. The Ivory Coast oven was not acceptable to fish smokers at Lake Chad, as they did not have sufficient funds to cover the cost of the oven and purchase fish to fill it. The drum fire chamber was found to be cumbersome. The poor colour of

the smoked product and the high variability of the oven temperature also militated against the Ivory Coast oven. (FAO, 2007).

Nyegezi oven

The Nyegezi oven, or fish smoking kiln, was designed by the Natural Resources Institute in the United Kingdom, and introduced first to Tanzania and later to Ghana in 1990. It was designed to heat fish solely by convection, isolating the fish from the fire to avoid direct heating by radiation. Air is heated in a furnace and diluted with air at ambient temperatures entering from ventilation holes at the side. After passing through the fish and heating it, the air enters a chimney, which channels it upwards. The suction created draws air into the furnace and dilution vents and maintains the current of hot air passing through the fish. The oven was originally designed to meet problems that were particularly significant in Tanzania: shortage of fuel, the fatty nature of the fish and the need to prepare a product that could keep for several weeks at ambient temperatures. In Ghana, the circumstances were significantly different and the oven did not offer any great fuel-saving advantages in producing the type of cured fish required in Ghana. (FAO, 2007).

PICTURES OF EXISTING NSPRI SMOKING KIIN



PLATE 1: Front View of the existing NSPRI Smoking kiln (Kamaldeen *et al.*, 2016)



PLATE 2: Rear View of the existing NSPRI Smoking kiln (Kamaldeen *et al.*, 2016)

CHAPTER THREE

MATERIALS AND METHODS

3.1 COMPONENTS OF THE EXISTING SMOKING KILN THAT WERE MODIFIED

- i. Non-rechargeable batteries were replaced with solar rechargeable batteries to reduce the long-term cost of production
- ii. Capacity of the smoker was upgraded by increasing the number of trays (size of the existing smoker was maintained)

Smoking kilns were lagged to conserve heat for efficient drying

3.2 MODIFICATION OF THE EXISTING SMOKING KILN

Findings from the preliminary investigations were used to specify the scope and re-design of modified smoking kiln

THE FINDINGS ARE:

- i. Low smoking rate.
- ii. Low capacity of the smoking kiln (40 kg per batch).
- iii. Excessive heat loss thereby reducing the thermal efficiency of the smoking kiln (smoking kiln not lagged)
- iv. High running cost.

3.3 RE-DESIGN CONSIDERATIONS AND PARAMETERS

In re-designing of the smoking kiln for medium scale fish processing the following were put into consideration.

- i. Medium capacity to serve the needs of both small and a medium scale processors.
- ii. Low operation and maintenance cost
- iii. Heat retention to improve thermal efficiency of the smoker.

3.4 DESIGN PARAMETERS

The design of the fish smoker was in accordance with the following: batch capacity (kg), amount of moisture to be removed, quantity of air required to effect drying, volume of air to effect drying, design and selection of blower, quantity of heat required, quantity of charcoal needed, rate of mass transfer and drying rate. The design calculations were based on the following specifications and assumptions: Minimum ambient temperature (T1) of 21°C and maximum average relative humidity (Rh) of 96 % of Kano state weather conditions (NIMET, 2014). Drying temperature in the smoker chamber (T2) was taken as 85 °C (Akande and Adeyemi, 2016). Six trays with dimension of 0.58 m (length) by 0.58 m (width). Density and specific heat capacity of catfish are 1059 kg m⁻³ and 3.63 kJ kg⁻¹.°C (Adeyemi and Akande, 2011). Moisture content of fresh fish is 75 %, (m.c) wb (Umar, 2016). Dried moisture content of 15% based on safe storage moisture content of fish reported by Oparaku and Mgbenka, (2012)

3.4.1 Batch capacity (kg)

The batch capacity of the kiln was estimated according to Crapiste and Rotstein (1997): From the specifications and assumptions made, as:

$$A_p = nL_tW_t \quad (2)$$

Where,

A_p = Area to be occupied by fish in the drying chamber

n = No. of trays

L_t = Tray Length = 0.58 m (from the existing smoking kiln)

W_t = Tray Width = 0.58 m (from the existing smoking kiln)

$$A_p = 6 \times 0.58 \times 0.58$$

$$A_p = 2.02 \text{ m}^2$$

$$\text{Capacity, } M = \rho_p A_p d \quad (3)$$

Where,

M = Kiln capacity (kg/batch)

ρ_p = bulk density of fresh fish

A_p = Area to be occupied by fish in the drying chamber

d = Tray depth = 0.028 m (from the existing smoking kiln)

$$M = 1059 \times 2.02 \times 0.028$$

$$M = 60 \text{ kg (per batch)}$$

3.4.2 Amount of moisture to be removed in kg (MR):

This is given by Ichsani and Dyah (2002) as:

$$M_R = M \times \left(\frac{Q_1 - Q_2}{1 - Q_2} \right) \quad (4)$$

Where,

M = smoking capacity per batch (60 kg)

Q_1 = initial moisture content of the fish to be dried = (75 %) Umar (2016) wb

Q_2 = Desired final moisture content based on safe storage

moisture content of fish (Oparaku and Mgbenka, 2012) = 15 %

$$M_R = 60 \times \left(\frac{0.75 - 0.15}{1 - 0.15} \right)$$

Therefore amount of moisture to be removed = 42.353 kg.

3.4.3 Smoking Rate (sr)

Smoking rate was determined using the expression by Donald (1974) give as:

$$s_r = \frac{M_R}{t} \quad (5)$$

Where,

t = time taken to smoke the fish (assume 4 hours)

Therefore,

$$s_r = \frac{42.353}{4}$$

$$s_r = 10.588 \text{ kg/h}$$

3.4.4 Mass of air required to Effect drying in kg/h (Ma).

This was calculated as (Akande and Adeyemi 2016):

$$M_a = \frac{d_r}{H_{r2} - H_{r1}} \quad (6)$$

Where,

H_{r1} and H_{r2} = initial and final humidity ratio in kg/kg dry air, respectively

Using the ambient temperature (T1) of 21°C, average relative humidity (Rh) of 96 % and drying temperature in the smoking kiln chamber (T2) of 85 °C. The initial humidity ratio H_{r1} is determined to be 0.0150 kg/kg dry air using the online psychometric calculator under normal

temperature and 1.01325 bar barometric pressure (Sugartech, 2018). When the heat is supplied, the temperature of the air rises to 85 °C giving the final humidity ratio H_{r2} as 0.2151 kg/kg dry air.

$$M_a = \frac{10.588}{0.2151 - 0.0150}$$

$$M_a = 52.915 \text{ kg/h}$$

3.4.5 Volumetric flow rate of the drying air (m³/s)

The volume of drying per unit time required was calculated as given by Akande and Adeyemi (2016):

$$m_v = M_a \times V_s \quad (7)$$

Where,

m_v = volumetric flow rate of the drying air in (m³/s)

M_a = mass of air required for effective drying = 52.915 kg/h (from eqn 6)

V_s = specific volume of the drying air = 1.3618 (m³kg⁻¹) Psychrometric chart

$$m_v = 52.915 \times 1.3618$$

$$m_v = 72.06 \text{ m}^3/\text{h} \quad \text{or} \quad m_v = 0.02 \text{ m}^3/\text{s}$$

Therefore, when converted to Cubic feet per minute (CFM) using the conversion factor

$$1\text{CFM} = 1.6990 \text{ m}^3/\text{h}$$

$$m_v = 72.06 \text{ m}^3/\text{h} = 42.41 \text{ CFM}$$

3.4.6 Design and selection of size and type of fan to convey the drying air

The blower serves the purpose of transferring heated air from the heat chamber to the dryer chamber. The power required to drive the blower was determined according to Henderson and Perry (1966) as simplified by Eckelman and Baker (1976) in Equation (8):

$$H_p = \frac{P_w \times m_v}{6356 \times e} \quad (8)$$

Where;

H_p = Motor horse power

P_w = pressure in inches of water, 18 (But , 2009)

e = fan efficiency, (45%) Ehiem, (2008)

m_v = volumetric flow rate of the drying air from eqn 7

$$H_p = \frac{18 \times 72.06}{6356 \times 45}$$

$$H_p = 0.0045$$

But

1 horsepower hp = 745.70 watts W (Denholm, and Margolis, (2006)).

Therefore,

$$H_p = 0.0045 \text{ or } (3.4 \text{ watts})$$

3.4.7 Heat required for smoking (H_r) in kJ

This is given by Ehiem *et al.* (2009) as:

$$H_r = (M \times H_K) + (H_L \times M_R) \quad (9)$$

Where,

H_r = Heat required for smoking kJ

M = Smoking kiln capacity per batch (60 kg)

$$H_K = CT(T_2 - T_1)$$

Whereas,

CT = Specific heat of fish 3.5 kJ/kg

T₁ = ambient temperature

T₂ = temperature in the smoker chamber

$$T_2 - T_1 = 85 - 21 = 64 \text{ }^\circ\text{C}$$

H_L = Latent heat of vaporization of fish = 1200 kJ/kg (Donald, 1974)

M_R = Amount of moisture to be removed (42.353 kg)

$$H_r = (M \times H_K) + (H_L \times M_R)$$

$$H_r = (60 \times 224) + (1200 \times 42.353)$$

$$H_r = (13440 + 50823.6)$$

$$H_r = 64263.6 \text{ kJ}$$

3.4.8. Determination of quantity of charcoal needed for combustion:

The quantity of charcoal needed to be burned in the combustion chamber was determined according to Axtell (2002) as:

$$Q_c = \frac{H_r}{C_c} \quad (10)$$

Where,

Q_c = quantity of charcoal needed for combustion (kg)

H_r = amount of heat energy required for drying (from eqn 6, 88501.2 kJ)

C_c = Calorific value of charcoal (7000 kJ/kg) Umar, 2016

$$Q_c = \frac{64263.6}{7000}$$

$$Q_c = 9.2 \text{ kg}$$

3.4.9 Solar system selection

In the Selection of solar panel and battery, solar sizer Xcel, version 1.9 was used as recommended by Denholm and Margolis, (2006). The following design data were used:

- i. Fan Power requirements: for two fans, each fan 16.4watts capacity. Therefore the total power requirement by the two fans will be 32.8watts.
- ii. Time of operation: the drying process is achieved in 6 hours in the existing machine. However, the modified smoking kiln was designed for four hours.
- iii. Sunshine hours: average sunshine hours in Kano state is 8.32 hours (NIMET, 2016).

The above data were used in selecting the appropriate Solar panel and Battery by using solar Sizer Xcel, Version 1.9 as shown in figure 3.1

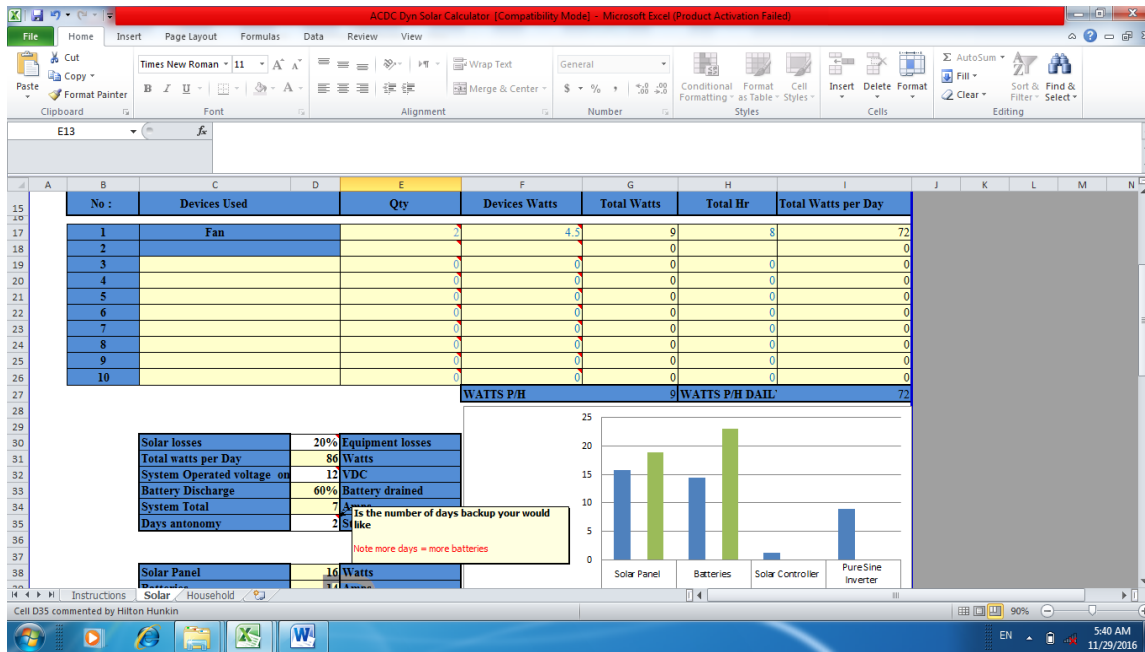


Figure 3.1 Solar Sizer Xcel, Version 1.9

Solar panel size 75watt

Battery size 48Ah

3.4.10 Thermal resistance due to Lagging R_{value} (K/W)

Rigid polyurethane foam 0.03 m thickness with thermal conductivity of 0.02 W/mK and packing density of 80 kg m⁻³ was encased in between two metal sheets of 45 W/mK thermal conductivity and thickness of 0.002 m.

Considering the thermal resistance before lagging R1 and thermal resistance after lagging R2 for unit area of the combustion chamber as given by Holman (2002):

$$R1 = \frac{\Delta x1}{k1} \quad (11)$$

$$R1 = \frac{0.002}{45} = 4.44 \times 10^{-5} K/W$$

$$R2 = \left(2 \times \frac{\Delta x1}{k1} + \frac{\Delta x2}{k2} \right) \quad (12)$$

$$R2 = \left(2 \times \frac{0.002}{45} + \frac{0.03}{0.02} \right) = 1.50 K/W$$

Where,

$\Delta x1$ = thickness of mild sheet 0.002 m

$\Delta x2$ = thickness of polyurethane foam 0.03m

$k1$ = thermal Conductivity of mild steel = 45 W/mK

$k2$ = thermal Conductivity of polyurethane foam = 0.02 W/mK

3.4.11 Smoking chamber

The volumetric capacity of smoking chamber was calculated in relation to the equation given by

John (2005) as:

$$V = A \times W \quad (13)$$

Where,

V_c = Volume of smoking chamber (m³)

A = Surface area of smoking chamber (m²)

W = Width of smoking chamber (m)

Surface area (A) was calculated using equation given by John (2005) as:

$$A = H \times W \quad (14)$$

Where;

A = Surface area of smoking chamber (m²)

H = height of chamber (m) = 1.00m (from the existing smoking kiln)

W = Width of smoking chamber (m) = 0.60m

$$A = 1.00 \times 0.60$$

$$A = 0.6\text{m}^2$$

$$V_c = 0.6 \times 0.6$$

$$V_c = 0.36 \text{ m}^3$$

Increasing the smoker capacity

The existing smoking kiln comprises of four trays spaced at 30 cm. the trays spacing was reduced to 10 cm and two more trays were added to increase the capacity of the smoking chamber.

3.4.12 Smoking trays

The volumetric capacity of each fish tray was calculated in relation to the volume of fish it occupies.

The volume of the material can be calculated as given by Khurmi and Gupta (2005):

$$V_m = \frac{M}{\rho} \quad (15)$$

Where,

V_m = Volume of material (m³)

M = mass of the fish (kg)

ρ = bulk density of fish (kg/m³)

Volume of tray

$$V_t = L \times B \times d \quad (16)$$

(John, 2005)

Where;

L = length of tray (0.58m)

B = breadth of tray (0.58m)

d = depth of tray (0.028m)

$$V_t = 0.58 \times 0.58 \times 0.028$$

$$V_t = 0.009 \text{ m}^3$$

3.4.13 Heat chamber

The volumetric capacity of charcoal pot was calculated in relation to the mass of charcoal.

Charcoal pot was design to contain 9.2 kg of charcoal per unit operation as shown above.

$$V_q = \frac{M_q}{\rho_q} \quad (17)$$

(Khurmi and Gupta,2005)

Where;

V_q = Volume of charcoal pot (m³)

M_q = mass of charcoal (kg)

ρ_q = bulk density of charcoal (kg/m³)

Therefore, the volumetric capacity of charcoal pot was determine by:

$$V_q = L \times B \times H \quad (18)$$

(John, 2005)

Where;

L = length of charcoal pot (0.61m) (from the existing smoking kiln)

B = breadth of charcoal pot (0.51m) (from the existing smoking kiln)

H = height of charcoal pot (0.31m) (from the existing smoking kiln)

$$V_q = 0.61 \times 0.51 \times 0.31$$

$$V_q = 0.096 \text{ m}^3$$

3.4.14 Oil Collector

$$V_o = L \times B \times H \tag{19}$$

Where,

L = length of oil collector (0.6 cm)

B = breadth of oil collector (0.3 cm)

H = height of oil collector (0.3 cm)

$$V_o = 0.6 \times 0.3 \times 0.3$$

$$V_o = 0.054 \text{ m}^3$$

3.5 MATERIAL SELECTION

The material selected for the smoking kiln components was based on the work they are expected to perform, the environmental condition in which they will function, their useful physical and mechanical properties, cost, toxicity of the materials and their availability in the market. Table 3.1 shows the material selected for the main components.

Table 3.1: Materials used for the Main Components of the fish smoker

S/N	Materials	Specification	Quantity
1	mild steel plate	Thickness 2 mm	3 standard size
2	Angle iron	45 x 45 x 2 mm	2 standard length
3	Rigid polyurethane foam	density of 80 kg m ⁻³	2 standard size
4	Stainless steel	Thickness 1 mm	2 standard size
5	Galvanized metal sheet	Thickness 1 mm	3 standard length
6	Wire mesh	2.5 m x 2.5 m	2 standard length
7	Pair of Hinges	90 mm size	5
8	Bearings	10 mm	4
9	Bolts and Nuts	M12 x 4 M10 x 3 M6 x 3	12 10 10
10	Fans	Axial fan with frame mover	2
11	Solar panel	80 W mono-crystalline photovoltaic (PV) cell	1
12	Battery	12 VDC battery	1
13	Charge regulator		1
14	Fan speed regulator		2

3.6 PRODUCTION COST

The production cost of the smoking kiln as at 1st November, 2017 was approximately N 133,782. The breakdown of the production cost is outlined in Table 3.2;

Table 3.2: Machine Production Cost

MATERIAL NEEDED	QUANTITY	UNIT PRICE (N)	TOTAL (N)
Mild Steel	5	6000	30000
Rigid polyurethane foam	2	5000	10000
Wire Mesh (2.5m x2.5m)	3	5000	15000
Angle Iron (45x45x2mm)	2	3000	6000
Bolt and Nuts		12	360
M12x4	30	10	160
M10x3	16	10	200
M6x3	20		
Fans	2	2000	4000
Solar Panel (80W mono-crystalline photovoltaic (PV) cell)	1	20000	20000
Battery (12V DC battery)	1	14000	14000
Charge regulator (2 Amp)	1	8500	8500
Speed regulator	2	500	1000
Paint (Finishing: Paints)	1 gallon	2500	2500
Bearings	4	100	400
Hinges (90mm size)	5	100	500
Galvinize Sheet Iron (Thickness 1mm)	3	3000	9000
10% Contingency			13,782
TOTAL			133,782

3.7 DESCRIPTION OF THE MODIFIED SMOKING KILN

The smoking kiln is trapezoidal shaped and detachable. It is double walled with polyurethane foam placed as lagging material between the inner and outer walls. The frame was constructed from angle iron, 45 mm by 45 mm. The materials of construction for the entire body are made of 1 mm galvanized iron sheets for the inner and outer walls, respectively, while the base is made of mild steel, 2 mm thick. The fish trays are made from galvanized wire mesh. The smoking kiln comprises of different units, these include: smoking chamber, heat chamber, heat circulation unit, and oil collection unit. Other the important component parts include the fan, the solar panel and battery.

The smoking chamber has a length of 1.00 m, width of 0.60 m and height of 1.00 m. The inner wall is made of galvanized steel. Galvanized steel was selected for its strength, heat transfer properties and cost. The compartment was constructed to house six fish trays. Oil collection unit consists of an open tray placed below the six fish trays and it is used to collect dropping oil from the smoked fish. The oil collection tray is made of galvanized sheet, 1.2 mm thick, and positioned at the bottom of trays. This also allows for free movement of the tray on the rack. The tray has a length of 0.58 m, and width of 0.58 m. The oil collection chamber is located at the lower region of the equipment and is separated from the fire place and the smoking chamber by insulated walls. The heat source is not directly placed under the smoking chamber; the hot air from the combustion chamber is conveyed to the smoking chamber by an axial fan centrally positioned at the back and facing the smoking chamber and the other fan distribute the hot air within the smoking chamber. The fan is powered by solar PV cell. The fan also ensures uniform distribution of heat and smoke within the smoking chamber. Plate 3.1 shows the perspective views of the equipment.

The chimney was designed to enhance the extraction of humid air/smoke mixture from the smoking chamber. It also conveys the exhaust air high above to reduce inhalation of smoke by the operator.



Plate 3.1: Side view of the modified Fish Smoking Kiln

3.8 PERFORMANCE EVALUATION OF THE SMOKING KILN

Performance evaluation of the modified smoking kiln was carried out using 600 kg of cat fish (*Clarias gariepinus*). Experiment were done in Three (3) replications, observations were made while operating the smoking kiln and relevant data were also collected. Method followed for each operations is presented in this section.

3.8.1 Performance Indicators

The following performance indicators were computed using the method reported by Adamu *et al.* (2013)

i.) Fish smoking rate (kg/h)

$$Sr = \frac{\text{Weight of smoked fish}}{\text{Time of smoking}} \quad (20)$$

Where,

SR = Smoking rate (kg/h)

$$SR = \frac{\text{Moisture removed}}{\text{Initial moisture content}} \times 100 \% \quad (21)$$

Where,

Moisture removed = initial moisture content – final moisture content

ii.) Fuel consumption rate (kg/h);

$$F_{cr} = \frac{F_c}{T_e} \quad (22)$$

Where,

F_{cr} = Fuel consumption rate (kg/h)

F_c = Fuel consumed during the smoking process (kg)

T_e = Effective smoking time (h).

3.8.2 Choice of Experimental Factors

The smoking kiln was evaluated using three factors, namely; Tray position, T, Heat source, C (kg) and fan speed, S(rpm).

i.) Tray position

Three tray position were used, namely; the Upper T1, Middle T2 and Lower T3 to test uniformity of fish smoking. This selection was made because preliminary study conducted established that there were difference in drying time between the trays.

ii.) Fuel source (kg)

Three different heat sources were used during the performance evaluation, namely; charcoal (C1), sawdust (C2) and rice husk (C3). This decision was made so that at end of the study suitable heat source will be recommended.

iii) Fan speed (rpm) (charcoal fan)

The Fan speeds were also applied in three (3) levels, these are; S1 =400 rpm, S2= 600 rpm and S3= 800 rpm. This decision was made so that at end of the study correct fan speed will be recommended. These various speed levels were determined experimentally by placing a digital tachometer at the fan spindle.

3.8.3 Experimental Design and Layout

The experiment was conducted using 3 x 3x 3 factorial experiment in a completely randomized design (CRD). Three (3) heat sources (C1, C2 and C3), three (3) different tray positions (T1, T2 and T3) and three (3) level of fan speeds (S1, S2 and S3) were used, combination of these factors gave 27 treatments. Each of these treatments were subjected to three (3) replications, thus

making the number of experiments conducted to be eighty one (81). While the outline of analysis of Variance (ANOVA) is presented in table 3.4.

Table 3.3: Experimental Layout for Performance Evaluation

R1	C1S1T1	C2S2T1	C3S3T1
	C3S2T2	C1S2T2	C2S1T2
	C2S3T3	C3S1T3	C1S3T3
	C3S3T1	C2S3T1	C1S1T1
	C2S1T2	C1S3T2	C2S3T2
	C1S2T3	C3S2T3	C3S3T3
	C1S3T1	C2S1T1	C3S1T1
	C2S2T2	C3S3T2	C1S2T2
	C3S1T3	C1S1T3	C2S2T3
R2	C1S1T1	C2S2T1	C3S3T1
	C3S2T2	C1S2T2	C2S1T2
	C3S1T3	C2S1T3	C2S2T3
	C3S3T1	C2S3T1	C1S1T1
	C2S1T2	C3S1T2	C2S3T2
	C1S2T3	C1S3T3	C3S2T3
	C1S3T1	C3S2T1	C3S1T1
	C2S3T2	C3S3T2	C1S2T2
	C2S2T3	C1S1T3	C1S3T3
R3	C1S1T2	C2S3T3	C1S1T1
	C2S2T2	C1S2T3	C2S2T1
	C3S3T2	C3S1T3	C3S3T1
	C3S1T2	C2S1T3	C3S1T1
	C3S2T2	C3S3T3	C2S3T1
	C1S2T2	C1S3T3	C1S2T1
	C1S3T2	C2S2T3	C1S3T1
	C2S1T2	C3S2T3	C3S2T1
	C2S3T2	C1S1T3	C2S1T1

Table 3.4 Outline of the Analysis of Variance for a 3 x 3 x 3 Factorial Experiments.

Source of variation`	Degrees of freedom	Sum of Squares	Mean Square	F Value
Heat source (C)	C-1=2			
fan speed (S)	S-1=2			
Tray level (T)	T-1=2			
SC	(S-1)(C-1)=4			
ST	(S-1)(T-1)=4			
CT	(C-1)(T-1)=4			
SCT	(S1)(C1)(T1)=8			
Error	(SCT-1)(r1)=54			
Total	rCST-1=80			

3.8.4 Sample Preparation

Fresh water catfish (*Clarias gariepinus*) was used for the test because this species is the most cultured fish species in Nigeria and therefore commercially important (Haruna, 2006). Samples were obtained from Court road, Kano (Plate 3.1). Thereafter, dirt and foreign materials were removed manually. The fish was checked physically with thorough cleaning, bled and gutted to remove blood and guts, and cleaned in potable water. The cleaned fish were folded into horseshoe shape, spread on the fish trays, allowed to drain for about 10 min and then transferred to the smoking kiln where the trays were arranged on the racks.



Plate 3.2: Cat fish *Clarias gariepinus*

3.8.5 Experimental Procedures

The performance test of the smoking kiln was carried out using charcoal, rice husk and saw dust at constant weight of 9 kg. The three (3) tray positions were also leveled. The fish samples were weighed and their weight recorded. The samples were then arranged on the trays as shown in plate 3.2. The samples in the smoking chamber were exposed to hot air while the fan at different speed levels blows and maintains hot air speed in the smoking chamber. The fish were allowed to dry to equilibrium moisture content. Changes in weight of fish samples on a tray were monitored using electronic balance with an accuracy of ± 0.01 g at intervals of 30 minutes during the smoking/drying period. The drying process was terminated in each case when equilibrium moisture content (EMC) of the dried fish samples was achieved. The total time spent for each experiment and weight of fish obtained were measured and recorded accordingly. The data recorded were used in the computations of the performance parameters; (Smoking rate, smoking efficiency and fuel consumption rate).



Plate 3.3: Improved Fish Smoker in Operation

3.8.6 Analysis of the Data

The data obtained from the performance evaluation were analyzed using SAS package. Further analysis was done to compare treatment means that were statistically significant using least significant difference (LSD).

CHAPTER FOUR

RESULTS AND DISCUSSION

The results of the performance evaluation for the modified fish smoker and the discussions are presented in the following sections.

4.1 SMOKING EFFICIENCY

The analysis of variance (ANOVA) results for smoking efficiency are as shown in Table 4.1. the results show that the effects of heat source, fan speed and their interactions are highly significant (1 %) on smoking efficiency. The effect of tray position was not significant. This implies that there is even distribution of heat inside the smoking kiln. This trends agree with results reported by Rahman, (2006) and Mujumdar, (2005) for fish dryers.

The best combination of variables which give the highest smoking efficiency (64.06 %) is at speed of S₃ (800 rpm) and charcoal (C₁).

Table 4.1: Analysis of Variance for Smoking Efficiency

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Calculate F	Tabulated F 5%
Replication	2	1339.15588	669.57794	9.82	3.29
Heat Source (C)	2	14011.91393	7005.95696	102.77**	3.29
Fan Speed (S)	2	1134.02605	567.01302	8.32**	3.29
Tray position (T)	2	210.77409	105.38705	1.55NS	3.29
Interactions:					
C*S	4	1080.86083	270.21521	3.96**	2.66
C*T	4	331.61936	82.90484	1.22NS	2.66
S*T	4	70.70909	17.67727	0.26NS	2.66
C*S*T	8	507.57771	63.44721	0.93NS	
Error	54	3544.85752	68.17034		
Total	80	22231.49445			

Note: NS = Not Significant, ** = Significant at 1% Probability level

Table 4.2 presents the results of further analysis using LSD for factors that are significant on the smoking efficiency. The results show that smoking efficiency increase with increase in fan speed. This agrees with Rahman (2006) and Majumdar (2005). Smoking efficiency was highest (48.42 %) at S3 (800 rpm), and least smoking efficiency (40.18 %) was observed at S1 (400 rpm).

The results for the heat source (C) show that saw dust (C2 and rice husk (C3) are statistically at par and lower than Charcoal (C1).

The best combination of variables which give the highest smoking efficiency (64.06 %) is at speed of S₃ (800 rpm) and charcoal (C₁).

Table 4.2: LSD for Smoking (SE) for the Main Effects

Treatments	Smoking efficiency (%)	LSD
C1	64.06	A
C2	36.55	B
C3	35.78	B
S3	48.42	A
S2	47.78	A
S1	40.18	B

Note: Means with the same letters are not significantly different.

4.2 SMOKING RATE

The analysis of variance (ANOVA) for smoking rate results is shown in Table 4.3. The results show that the effects of Heat source (C) is highly significant (1 % level) on smoking rate. This agrees with findings of Rahman, (2006) and Majumdar, (2005) for fish dryers. Fan speed and the Tray position (T) were not significant. All the interactions were not significant

Table 4.3: Analysis of Variance for Smoking Rate

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Calculate F	Tabulated F 5%
Replication	2	2650.128200	1325.064100		
Heat Source (C)	2	9411.676119	4705.838059	34.00**	3.29
Speed (S)	2	245.264363	122.632181	0.89NS	3.29
Tray (T)	2	341.688385	170.844193	1.23NS	3.29
Interactions:					
C*S	4	799.289919	199.822480	1.44NS	2.66
C*T	4	549.624785	137.406196	0.99NS	2.66
S*T	4	208.722252	52.180563	0.38NS	2.66
C*S*T	8	2029.855333	253.731917	1.83	
Error	54	7197.85287	138.42025		
Total	80	23434.10222			

Note: N = Not Significant, * = Significant at 5% Probability level, ** = Significant at 1% Probability level

The LSD results for the heat source (C) shows that mean values of smoking rate for charcoal (C1) and Saw dust (C2) are statistically at par and higher than those for rice husk. The best combination which gives highest smoking rate (58.59 kg/h) is the one using either charcoal (C1) or sawdust (C2) at a speed of S₁(400 rpm). The phenomenon agreed with assertions of Fellows (2000).

Table 4.4: LSD for Smoking Rate (SR) for the Main Effects

Treatments	Smoking Rate (g/min)	LSD
C1	58.59	A
C2	56.23	A
C3	34.64	B
S1	52.26	A
S2	48.86	A
S3	48.33	A

Note: Means with the same letters are not significantly different.

4.3 OUTPUT CAPACITY OF THE MODIFIED SMOKING KILN USING DIFFERENT HEAT SOURCES.

The results of the output capacity of the smoking kiln using three different heat sources is presented in Table 4.5

Table 4.5: Output capacity of the developed fish smoker with different heat sources

S/N	Output capacity (kg/h)		
	Charcoal	Sawdust	Rice husk
1	17.14	13.33	12.00
2	15.00	15.00	10.91
3	20.00	12.00	12.00
Mean	17.38	13.44	11.64

Table 4.6 presents the ANOVA for the Output Capacity. Results show that the effect of heat source (C), speed (S) and the interactions of heat source, speed and tray positions are significant at (5 % level). This trend agrees with findings of Umar, (2000) and Rahman (2006).

Further analysis using LSD Table 4.7 shows that Sawdust and Rice husk heat sources are statistically at par but lower than the mean values for Charcoal (C₁). The mean Output Capacity values for Speeds 600 rpm (S₂) and 400 rpm (S₁) are statistically at par but lower than mean values for S₁ (800 rpm).

The best combination which gives the highest mean values of output capacity (93.94 kg/h) is the one with a speed (S₃) of 800 rpm using Charcoal as heat source at tray position T₁.

There is 159 % increase in output capacity of the modified smoker when compared with the existing smoker.

Table 4.6: Analysis of Variance for Output Capacity (Kg/h)

Sources of Variation	Degree of Freedom	Sum of Square	Mean Square	Calculate F	Tabulated F 5%
Replication	2	1036.050239	518.025119	5.91*	
Heat Source (C)	2	912.547561	456.273781	5.21*	3.29
Speed (S)	2	814.529563	407.264782	4.65*	3.29
Tray (T)	2	80.600954	40.300477	0.46NS	3.29
Interactions:					
C*S	4	908.551443	227.137861	2.59NS	2.66
C*T	4	415.143921	103.785980	1.18NS	2.66
S*T	4	162.106689	40.526672	0.46NS	2.66
C*S*T	8	2549.146534	318.643317	3.64*	
Error	54	4558.21390	87.65796		
Total	80	11436.89080			

Note: N = Not Significant, * = Significant at 5% Probability level, ** = Significant at 1% Probability level

Table 4.7: LSD for Output Capacity (OC) for the Main Effects

Treatments	Output Capacity (Kg/h)	LSD
C1	93.94	A
C2	88.07	B
C3	86.02	B
S1	93.42	A
S2	88.93	B
S3	85.68	B

Note: Means with the same letters are not significantly different.

4.4 FUEL CONSUMPTION

The results of the fuel consumption of the smoking kiln using three different heat sources are presented in Table 4.8

Table 4.8: Fuel consumption of the developed fish smoker with different heatsources

S/N	Fuel consumption (kg/h)		
	Charcoal	Sawdust	Rice husk
1	2.00	3.11	4.20
2	1.75	3.50	3.80
3	2.33	2.80	4.20
Mean	2.01	3.14	4.06

The results show that the mean values of fuel consumption for the smoking kiln were 2.01, 3.14 and 4.06 for charcoal, sawdust and rice husk respectively. This implies that the smoking kiln consumes more rice husk followed by saw dust and the least in fuel consumption is charcoal.

This trend may be as results of their differences in density and their calorific values.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 SUMMARY

A fish smoking kiln was modified to address the limitations of an existing fish smoking kiln developed by NSPRI (2014). Performance tests were carried out using cat fish, using Completely Randomized Design (CRD) in 3 x 3 x 3 factorial experiment.

The smoking kiln was evaluated using smoking efficiency (%), smoking rate (kg/h), output capacity (kg/h), and fuel consumption rate (kg/h) as performance indicators while heat source, fan speed, and tray level were used as independent variables. The independent variables have significant effect on the performance indicators. The results obtained from the performance evaluation of the fish smoker revealed that the highest mean smoking efficiency of 95 % was obtained and when compared to 70 % achieved with the existing fish smoker this represents an increase of 35 % from the smoking efficiency achieved with the existing fish smoker. The highest mean output capacity of 17.38 kg/h was achieved and when compared to 6.7 kg/h achieved with the existing fish smoker represents 159 % increase in output capacity.

5.2 CONCLUSIONS

The following conclusions were made:

1. The heat source and fan speeds have a significant influence on the smoking efficiency, output capacity and fuel consumption rate.
2. Highest mean Smoking efficiency (64.06 %) was achieved at the combination of charcoal (C₁) (7kg) and fan speed (S₃) of 800 rpm.
3. Highest mean Smoking rate (58.59 kg/h) was achieved at the combination using either charcoal or saw dust at a speed of S₁ (400 rpm).
4. Highest mean output capacity of 17.38 kg/h was achieved at the variable combination of 800 rpm, and 7 kg/h for fan speed and charcoal.
5. Lowest mean output capacity of 11.64 kg/h was obtained with the combination of 400 rpm,(Fan speed) and 21 kg rice husk.
6. Lowest mean fuel consumption rate of 2.01 kg/h was obtained with the combination of 800 rpm, (Fan speed) and 7 kg Charcoal..

5.3 RECOMMENDATIONS

The following recommendations are made for further modification and evaluation of the smoking kiln;

1. Further studies to modify and evaluate the smoking kiln using other species of fish should be conducted.
2. The smoking kiln should also be evaluated using meat to make it more versatile thereby increasing its acceptability among end-users.

3. Optimization of the variables should be considered to harmonize higher (e.g output capacity, drying efficiency).
4. Smoke filter should be installed to reduce polycyclic aromatic hydrocarbon
5. External thermometer should be installed to help the operator regulate system temperature.

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APPENDICES

Appendice I

The SAS System

00:48 Friday, July 23, 1993 1

The GLM Procedure

Class Level Information

Class	Levels	Values
REP	3	1 2 3
HS	3	1 2 3
SP	3	1 2 3
TR	3	1 2 3

Number of observations 81

The GLM Procedure

Dependent Variable: OC

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	28	6878.67690	245.66703	2.80	0.0006
Error	52	4558.21390	87.65796		
Corrected Total	80	11436.89080			

R-Square	Coeff Var	Root MSE	OC Mean
0.601446	10.47929	9.362583	89.34370

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REP	2	1036.050239	518.025119	5.91	0.0049
HS	2	912.547561	456.273781	5.21	0.0087
SP	2	814.529563	407.264782	4.65	0.0139
HS*SP	4	908.551443	227.137861	2.59	0.0472
TR	2	80.600954	40.300477	0.46	0.6340
HS*TR	4	415.143921	103.785980	1.18	0.3288
SP*TR	4	162.106689	40.526672	0.46	0.7630
HS*SP*TR	8	2549.146534	318.643317	3.64	0.0020

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	2	1036.050239	518.025119	5.91	0.0049
HS	2	912.547561	456.273781	5.21	0.0087
SP	2	814.529563	407.264782	4.65	0.0139
HS*SP	4	908.551443	227.137861	2.59	0.0472
TR	2	80.600954	40.300477	0.46	0.6340
HS*TR	4	415.143921	103.785980	1.18	0.3288
SP*TR	4	162.106689	40.526672	0.46	0.7630
HS*SP*TR	8	2549.146534	318.643317	3.64	0.0020

The GLM Procedure

Dependent Variable: SR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	28	16236.24936	579.86605	4.19	<.0001
Error	52	7197.85287	138.42025		
Corrected Total	80	23434.10222			

R-Square	Coeff Var	Root MSE	SR Mean
0.692847	23.61474	11.76521	49.82148

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REP	2	2650.128200	1325.064100	9.57	0.0003
HS	2	9411.676119	4705.838059	34.00	<.0001
SP	2	245.264363	122.632181	0.89	0.4185
HS*SP	4	799.289919	199.822480	1.44	0.2329
TR	2	341.688385	170.844193	1.23	0.2994
HS*TR	4	549.624785	137.406196	0.99	0.4199
SP*TR	4	208.722252	52.180563	0.38	0.8240
HS*SP*TR	8	2029.855333	253.731917	1.83	0.0917

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	2	2650.128200	1325.064100	9.57	0.0003
HS	2	9411.676119	4705.838059	34.00	<.0001
SP	2	245.264363	122.632181	0.89	0.4185
HS*SP	4	799.289919	199.822480	1.44	0.2329
TR	2	341.688385	170.844193	1.23	0.2994
HS*TR	4	549.624785	137.406196	0.99	0.4199
SP*TR	4	208.722252	52.180563	0.38	0.8240
HS*SP*TR	8	2029.855333	253.731917	1.83	0.0917

The GLM Procedure

Dependent Variable: SE

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	28	18686.63693	667.37989	9.79	<.0001
Error	52	3544.85752	68.17034		
Corrected Total	80	22231.49445			

R-Square	Coeff Var	Root MSE	SE Mean
0.840548	18.16106	8.256533	45.46284

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REP	2	1339.15588	669.57794	9.82	0.0002
HS	2	14011.91393	7005.95696	102.77	<.0001
SP	2	1134.02605	567.01302	8.32	0.0007
HS*SP	4	1080.86083	270.21521	3.96	0.0070
TR	2	210.77409	105.38705	1.55	0.2227
HS*TR	4	331.61936	82.90484	1.22	0.3152
SP*TR	4	70.70909	17.67727	0.26	0.9027
HS*SP*TR	8	507.57771	63.44721	0.93	0.4994

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	2	1339.15588	669.57794	9.82	0.0002
HS	2	14011.91393	7005.95696	102.77	<.0001
SP	2	1134.02605	567.01302	8.32	0.0007
HS*SP	4	1080.86083	270.21521	3.96	0.0070
TR	2	210.77409	105.38705	1.55	0.2227
HS*TR	4	331.61936	82.90484	1.22	0.3152
SP*TR	4	70.70909	17.67727	0.26	0.9027
HS*SP*TR	8	507.57771	63.44721	0.93	0.4994

The GLM Procedure

t Tests (LSD) for OC

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	87.65796
Critical Value of t	2.67373
Least Significant Difference	6.8131

Means with the same letter are not significantly different.

t	Grouping	Mean	N	HS
	A	93.940	27	1
	A			
B	A	88.073	27	3
B				
B		86.018	27	2

The GLM Procedure

t Tests (LSD) for SR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	138.4202
Critical Value of t	2.67373
Least Significant Difference	8.5615

Means with the same letter are not significantly different.

t Grouping	Mean	N	HS
A	58.596	27	3
A			
A	56.230	27	2
B	34.639	27	1

The GLM Procedure

t Tests (LSD) for SE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	68.17034
Critical Value of t	2.67373
Least Significant Difference	6.0083

Means with the same letter are not significantly different.

t Grouping	Mean	N	HS
A	64.058	27	1
B	36.554	27	2
B	35.777	27	3

The GLM Procedure

t Tests (LSD) for OC

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	87.65796
Critical Value of t	2.67373
Least Significant Difference	6.8131

Means with the same letter are not significantly different.

t Grouping	Mean	N	SP
A	93.417	27	3
A			
B A	88.933	27	2
B			
B	85.682	27	1

The GLM Procedure

t Tests (LSD) for SR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	138.4202
Critical Value of t	2.67373
Least Significant Difference	8.5615

Means with the same letter are not significantly different.

t Grouping	Mean	N	SP
A	52.263	27	1
A			
A	48.868	27	3
A			
A	48.334	27	2

The GLM Procedure

t Tests (LSD) for SE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	68.17034
Critical Value of t	2.67373
Least Significant Difference	6.0083

Means with the same letter are not significantly different.

t Grouping	Mean	N	SP
A	48.416	27	3
A			
A	47.789	27	2
B	40.184	27	1

The GLM Procedure

Level of HS	Level of SP	N	-----OC-----		-----SR-----		-----SE-----	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	1	9	91.025200	7.7786415	42.2300000	6.0935622	54.4088889	6.1488626
1	2	9	87.662200	11.4082061	31.0144444	11.1820773	65.8144444	8.4721973
1	3	9	103.132000	13.8404918	30.6711111	13.2082971	71.9500000	10.2560823
2	1	9	82.057200	5.3147105	59.1677778	8.4011499	29.4666667	7.2958636
2	2	9	90.016300	12.4771379	54.0177778	16.9411605	42.4400000	11.0733994
2	3	9	85.980700	10.8401338	55.5055556	13.7462023	37.7555556	8.3605713
3	1	9	83.962900	12.8785777	55.3911111	17.0555823	36.6755556	11.6432900
3	2	9	89.119500	10.9942329	59.9688889	17.3714453	35.1111111	11.2949728
3	3	9	91.137300	11.3920849	60.4266667	12.0997603	35.5433333	5.1885716

The GLM Procedure

t Tests (LSD) for OC

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	87.65796
Critical Value of t	2.67373
Least Significant Difference	6.8131

Means with the same letter are not significantly different.

t Grouping	Mean	N	TR
A	90.726	27	3
A			
A	88.895	27	1
A			
A	88.410	27	2

The GLM Procedure

t Tests (LSD) for SR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	138.4202
Critical Value of t	2.67373
Least Significant Difference	8.5615

Means with the same letter are not significantly different.

t Grouping	Mean	N	TR
A	51.424	27	1
A			
A	51.119	27	3
A			
A	46.922	27	2

The GLM Procedure

t Tests (LSD) for SE

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	52
Error Mean Square	68.17034
Critical Value of t	2.67373
Least Significant Difference	6.0083

Means with the same letter are not significantly different.

t Grouping	Mean	N	TR
A	47.731	27	2
A			
A	44.536	27	3
A			
A	44.121	27	1

The GLM Procedure

Level of HS	Level of TR	N	-----OC-----		-----SR-----		-----SE-----	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	1	9	89.4558000	9.9876004	33.6466667	16.9950000	64.3333333	15.7918587
1	2	9	94.3882000	11.0070841	33.0744444	7.9524479	65.2844444	8.1200294
1	3	9	97.9754000	16.4038922	37.1944444	8.4064099	62.5555556	8.5686976
2	1	9	87.2138000	8.9404582	57.6800000	11.0214813	35.6211111	8.3867029
2	2	9	83.1782000	9.2482500	50.2411111	12.0753804	41.3011111	10.1832846
2	3	9	87.6622000	12.5652049	60.7700000	15.1378466	32.7400000	11.2305766
3	1	9	90.0163000	14.6271171	62.9444444	16.8574569	32.4077778	8.5112643
3	2	9	87.6622000	10.2074114	57.4511111	13.8551060	36.6088889	9.3596400
3	3	9	86.5412000	11.0493871	55.3911111	15.6866141	38.3133333	10.5214887

Level of SP	Level of TR	N	-----OC-----		-----SR-----		-----SE-----	
			Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	1	9	83.2903000	9.4523635	51.1566667	9.7985433	39.5188889	10.9819732
1	2	9	86.9896000	8.7631804	49.6688889	9.7819878	43.5466667	11.9348261
1	3	9	86.7654000	11.3585294	55.9633333	18.9852778	37.4855556	17.6877840
2	1	9	88.6711000	10.9993752	50.2411111	22.1556434	45.7811111	19.0546185
2	2	9	86.4291000	9.9108700	45.6633333	19.2557667	49.3800000	16.2841894
2	3	9	91.6978000	13.2262562	49.0966667	19.1175325	48.2044444	16.2690950
3	1	9	94.7245000	10.7062836	52.8733333	25.5431693	47.0622222	23.8128934
3	2	9	91.8099000	13.7039671	45.4344444	16.5718361	50.2677778	18.7600751
3	3	9	93.7156000	17.4851746	48.2955556	11.1106932	47.9188889	14.6343965

Level of HS	Level of SP	Level of TR	N	-----OC-----		-----SR-----	
				Mean	Std Dev	Mean	Std Dev
1	1	1	3	93.155100	5.7368482	46.6933333	7.4512035
1	1	2	3	95.845500	2.0178000	41.8866667	2.9733539
1	1	3	3	84.075000	9.5357508	38.1100000	5.3520370
1	2	1	3	86.092800	10.7878414	30.5566667	15.4614402
1	2	2	3	82.057200	5.5565879	28.8400000	4.4896659
1	2	3	3	94.836600	15.6623399	33.6466667	14.9379595
1	3	1	3	89.119500	14.5622172	23.6900000	21.0331952

Level of HS	Level of SP	Level of TR	N	-----SE-----	
				Mean	Std Dev
1	1	1	3	50.8800000	4.9222251
1	1	2	3	56.9600000	3.9460487
1	1	3	3	55.3866667	9.0309763
1	2	1	3	66.1433333	13.3958812
1	2	2	3	65.1166667	3.1898642
1	2	3	3	66.1833333	9.8178884
1	3	1	3	75.9766667	17.7228675

The GLM Procedure

Level of HS	Level of SP	Level of TR	N	-----OC-----		-----SR-----	
				Mean	Std Dev	Mean	Std Dev
1	3	2	3	105.261900	6.4073756	28.4966667	7.0110651
1	3	3	3	115.014600	0.0000000	39.8266667	0.5946708
2	1	1	3	82.057200	4.5493821	59.3966667	8.7600476
2	1	2	3	80.375700	5.9116145	52.1866667	6.8580780
2	1	3	3	83.738700	6.9898642	65.9200000	4.1200000
2	2	1	3	85.420200	7.2985623	49.4400000	7.2100000
2	2	2	3	90.464700	13.1673368	51.5000000	21.0331952
2	2	3	3	94.164000	18.3922590	61.1133333	23.1769073
2	3	1	3	94.164000	11.3398445	64.2033333	13.6774279
2	3	2	3	78.694200	3.4949321	47.0366667	8.3888636
2	3	3	3	85.083900	12.1627209	55.2766667	16.6507818
3	1	1	3	74.658600	6.6157997	47.3800000	9.9329603
3	1	2	3	84.747600	8.7953863	54.9333333	13.5996409
3	1	3	3	92.482500	17.3968221	63.8600000	25.9960247
3	2	1	3	94.500300	15.4112021	70.7266667	21.4658853
3	2	2	3	86.765400	11.6352024	56.6500000	19.0758670
3	2	3	3	86.092800	6.7175872	52.5300000	10.4533583
3	3	1	3	100.890000	3.6376407	70.7266667	5.6727977
3	3	2	3	91.473600	12.9726390	60.7700000	13.8572328
3	3	3	3	81.048300	6.4863195	49.7833333	5.6727977

Level of HS	Level of SP	Level of TR	N	-----SE-----	
				Mean	Std Dev
1	3	2	3	73.7766667	5.0822666
1	3	3	3	66.0966667	0.3178574
2	1	1	3	29.1766667	6.1793635
2	1	2	3	36.6266667	4.2719590
2	1	3	3	22.5966667	2.9435410
2	2	1	3	43.7400000	4.6526874
2	2	2	3	45.6033333	16.1814750
2	2	3	3	37.9766667	12.6319450
2	3	1	3	33.9466667	7.4925719
2	3	2	3	41.6733333	8.6000136
2	3	3	3	37.6466667	10.2320591
3	1	1	3	38.5000000	8.0243567
3	1	2	3	37.0533333	11.4450178
3	1	3	3	34.4733333	18.2867283
3	2	1	3	27.4600000	10.9335630
3	2	2	3	37.4200000	13.4633837
3	2	3	3	40.4533333	8.4193487
3	3	1	3	31.2633333	3.3875114
3	3	2	3	35.3533333	5.8747369
3	3	3	3	40.0133333	2.0479827

Appendix II

The GLM Procedure

Class Level Information

Class		Levels	Values
REP		3	1 2 3
D	5	1 2 3 4 5	
C	3	1 2 3	
S	3	1 2 3	
T	3	1 2 3	

Number of observations 404

The GLM Procedure

Dependent Variable: DR

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	136	45.60813415	0.33535393	25.43	<.0001
Error	267	3.52085657	0.01318673		
Corrected Total	403	49.12899071			

R-Square	Coeff Var	Root MSE	DR Mean
0.928334	28.71064	0.114833	0.399968

Source	DF	Type I SS	Mean Square	F Value	Pr > F
REP	2	0.20077517	0.10038759	7.61	0.0006
D	4	27.75660240	6.93915060	526.22	<.0001
C	2	6.89227520	3.44613760	261.33	<.0001
D*C	8	4.86517941	0.60814743	46.12	<.0001
S	2	0.70526550	0.35263275	26.74	<.0001
D*S	8	0.90898359	0.11362295	8.62	<.0001
C*S	4	0.60478398	0.15119599	11.47	<.0001
D*C*S1	6	2.25110033	0.14069377	10.67	<.0001
T	2	0.11916662	0.05958331	4.52	0.0118
D*T	8	0.10989267	0.01373658	1.04	0.4049
C*T	4	0.08472379	0.02118095	1.61	0.1730
D*C*T1	6	0.24031605	0.01501975	1.14	0.3189
S*T	4	0.07975531	0.01993883	1.51	0.1989
D*S*T1	6	0.18221862	0.01138866	0.86	0.6119
C*S*T	8	0.20228791	0.02528599	1.92	0.0576
D*C*S*T	32	0.40480761	0.01265024	0.96	0.5344

Source	DF	Type III SS	Mean Square	F Value	Pr > F
REP	2	0.18339891	0.09169945	6.95	0.0011
D	4	27.63025753	6.90756438	523.83	<.0001
C	2	6.85465094	3.42732547	259.91	<.0001
D*C	8	4.87316857	0.60914607	46.19	<.0001

S	2	0.70591714	0.35295857	26.77	<.0001
D*S	8	0.90378495	0.11297312	8.57	<.0001
C*S	4	0.59938780	0.14984695	11.36	<.0001
D*C*S	16	2.25423244	0.14088953	10.68	<.0001
T	2	0.11842353	0.05921177	4.49	0.0121
D*T	8	0.11060083	0.01382510	1.05	0.4000
C*T	4	0.08552045	0.02138011	1.62	0.1691
D*C*T	16	0.23725373	0.01482836	1.12	0.3320

The GLM Procedure

Dependent Variable: DR

Source	DF	Type III SS	Mean Square	F Value	Pr > F
SP*TR	4	0.07863363	0.01965841	1.49	0.2052
DU*SP*TR	16	0.18370170	0.01148136	0.87	0.6038
HS*SP*TR	8	0.20212683	0.02526585	1.92	0.0578
DU*HS*SP*TR	32	0.40480761	0.01265024	0.96	0.5344

The GLM Procedure

t Tests (LSD) for DR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	267
Error Mean Square	0.013187
Critical Value of t	2.59437
Least Significant Difference	0.0469
Harmonic Mean of Cell Sizes	80.798

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	D
A	0.76221	81	1
B	0.59232	81	2
C	0.40115	81	3
D	0.21832	81	4
E	0.02117	80	5

Tuesday, July 6, 1993 5

The SAS System

22:21

The GLM Procedure

t Tests (LSD) for DR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error

rate.

Alpha	0.01
Error Degrees of Freedom	267
Error Mean Square	0.013187
Critical Value of t	2.59437
Least Significant Difference	0.0363
Harmonic Mean of Cell Sizes	134.665

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	C
A	0.58343	135	1
B	0.31017	135	2
B			
B	0.30561	134	3

The GLM Procedure

Level of D	Level of C	N	-----DR----- Mean	Std Dev
1	1	27	1.17844444	0.43275427
1	2	27	0.56062963	0.09043789
1	3	27	0.54755556	0.06375454
2	1	27	0.89270370	0.25403480
2	2	27	0.46133333	0.11168569
2	3	27	0.42292593	0.10494465
3	1	27	0.55103704	0.10642602
3	2	27	0.32700000	0.10903599
3	3	27	0.32540741	0.09633326
4	1	27	0.27807407	0.16387611
4	2	27	0.19051852	0.09723222
4	3	27	0.18637037	0.09343165
5	1	27	0.01687407	0.03289816
5	2	27	0.01135556	0.01471938
5	3	26	0.03580769	0.05246029

Tuesday, July 6, 1993 7

The SAS System

22:21

The GLM Procedure

t Tests (LSD) for DR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error

rate.

Alpha	0.01
Error Degrees of Freedom	267
Error Mean Square	0.013187
Critical Value of t	2.59437
Least Significant Difference	0.0363
Harmonic Mean of Cell Sizes	134.665

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	S
A	0.44456	134	3
A			
A	0.41311	135	2
B	0.34257	135	1

The GLM Procedure

Level of D	Level of S	N	-----DR----- Mean	Std Dev
1	1	27	0.63903704	0.20480525
1	2	27	0.75348148	0.22211957
1	3	27	0.89411111	0.58676842
2	1	27	0.49185185	0.16474285
2	2	27	0.58611111	0.20249261
2	3	27	0.69900000	0.37262984
3	1	27	0.36237037	0.15669180
3	2	27	0.44970370	0.16620627
3	3	27	0.39137037	0.10586281
4	1	27	0.20403704	0.15798405
4	2	27	0.25103704	0.13141054
4	3	27	0.19988889	0.08188798
5	1	27	0.01555185	0.03655660
5	2	27	0.02519630	0.04527559
5	3	26	0.02280769	0.02955810

Level of C	Level of S	N	-----DR----- Mean	Std Dev
1	1	45	0.49218444	0.32707956
1	2	45	0.56940667	0.36673898
1	3	45	0.68868889	0.66426596
2	1	45	0.23865778	0.17988978
2	2	45	0.37317778	0.24424171
2	3	45	0.31866667	0.19957660
3	1	45	0.29686667	0.20175363
3	2	45	0.29673333	0.21269808
3	3	44	0.32363636	0.17819705

Level of D	Level of H	Level of S	N	-----DR----- Mean	Std Dev
1	1	1	9	0.89977778	0.11086679
1	1	2	9	1.04444444	0.02588489
1	1	3	9	1.59111111	0.54455795
1	2	1	9	0.47466667	0.06457554

1	2	2	9	0.66388889	0.03937780
1	2	3	9	0.54333333	0.01469694
1	3	1	9	0.54266667	0.05033389
1	3	2	9	0.55211111	0.09074200
1	3	3	9	0.54788889	0.04890921
2	1	1	9	0.68500000	0.09747436
2	1	2	9	0.80433333	0.04593201
2	1	3	9	1.18877778	0.20539522
2	2	1	9	0.35800000	0.08712921

The GLM Procedure

Level of	Level of	Level of	-----DR-----		
D	C	S	N	Mean	Std Dev
2	2	2	9	0.55388889	0.08846390
2	2	3	9	0.47211111	0.05780667
2	3	1	9	0.43255556	0.07093679
2	3	2	9	0.40011111	0.17222909
2	3	3	9	0.43611111	0.01459833
3	1	1	9	0.53288889	0.08684821
3	1	2	9	0.63411111	0.08217884
3	1	3	9	0.48611111	0.09817516
3	2	1	9	0.24300000	0.07731106
3	2	2	9	0.39344444	0.09479466
3	2	3	9	0.34455556	0.10209935
3	3	1	9	0.31122222	0.12079195
3	3	2	9	0.32155556	0.11725198
3	3	3	9	0.34344444	0.03482137
4	1	1	9	0.33766667	0.18767059
4	1	2	9	0.32900000	0.14371413
4	1	3	9	0.16755556	0.10369199
4	2	1	9	0.11322222	0.04567488
4	2	2	9	0.24100000	0.10987152
4	2	3	9	0.21733333	0.07855253
4	3	1	9	0.16122222	0.11126857
4	3	2	9	0.18311111	0.10609364
4	3	3	9	0.21477778	0.05570408
5	1	1	9	0.00558889	0.00446275
5	1	2	9	0.03514444	0.05240193
5	1	3	9	0.00988889	0.01333646
5	2	1	9	0.00440000	0.00363215
5	2	2	9	0.01366667	0.01805547
5	2	3	9	0.01600000	0.01674067
5	3	1	9	0.03666667	0.05964059
5	3	2	9	0.02677778	0.05767534
5	3	3	8	0.04500000	0.04194895

The GLM Procedure

t Tests (LSD) for DR

NOTE: This test controls the Type I comparisonwise error rate, not the experimentwise error rate.

Alpha	0.01
Error Degrees of Freedom	267
Error Mean Square	0.013187
Critical Value of t	2.59437
Least Significant Difference	0.0363
Harmonic Mean of Cell Sizes	134.665

NOTE: Cell sizes are not equal.

Means with the same letter are not significantly different.

t Grouping	Mean	N	T
A	0.42264	135	2
A			
B A	0.39510	134	3
B			
B	0.38213	135	1

The GLM Procedure

Level of D	Level of T	N	-----DR----- Mean	Std Dev
1	1	27	0.75774074	0.40650694
1	2	27	0.80651852	0.39700449
1	3	27	0.72237037	0.37803776
2	1	27	0.54459259	0.26235593
2	2	27	0.62618519	0.27301860
2	3	27	0.60618519	0.28672461
3	1	27	0.38674074	0.14980028
3	2	27	0.41729630	0.13513151
3	3	27	0.39940741	0.16218135
4	1	27	0.20100000	0.13028814
4	2	27	0.24062963	0.12735026
4	3	27	0.21333333	0.12869433
5	1	27	0.02060000	0.03899822
5	2	27	0.02255556	0.04364131
5	3	26	0.02030769	0.02973452

Level of C	Level of T	N	-----DR----- Mean	Std Dev
1	1	45	0.56414667	0.48302265
1	2	45	0.61186667	0.49939835
1	3	45	0.57426667	0.46773105
2	1	45	0.30963556	0.22205803
2	2	45	0.34004444	0.22281066
2	3	45	0.28082222	0.20114957
3	1	45	0.27262222	0.17744235
3	2	45	0.31600000	0.19704810
3	3	44	0.32872727	0.21551176

Level of D	Level of C	Level of T	N	-----DR----- Mean	Std Dev
1	1	1	9	1.21455556	0.41335158
1	1	2	9	1.26188889	0.39271250
1	1	3	9	1.05888889	0.50811870
1	2	1	9	0.56511111	0.08929788
1	2	2	9	0.59300000	0.08103549

1	2	3	9	0.52377778	0.09649712
1	3	1	9	0.49355556	0.05652237
1	3	2	9	0.56466667	0.03279863
1	3	3	9	0.58444444	0.06163423
2	1	1	9	0.81166667	0.24731407
2	1	2	9	0.93277778	0.27089933
2	1	3	9	0.93366667	0.25318274
2	2	1	9	0.47033333	0.12943145

The GLM Procedure

Level of D	Level of C	Level of T	-----DR-----		
			N	Mean	Std Dev
2	2	2	9	0.50566667	0.07581392
2	2	3	9	0.40800000	0.11196875
2	3	1	9	0.35177778	0.13232420
2	3	2	9	0.44011111	0.04557808
2	3	3	9	0.47688889	0.08308647
3	1	1	9	0.52733333	0.14769563
3	1	2	9	0.56311111	0.05830618
3	1	3	9	0.56266667	0.10319520
3	2	1	9	0.33233333	0.10960953
3	2	2	9	0.36022222	0.10351422
3	2	3	9	0.28844444	0.11385639
3	3	1	9	0.30055556	0.07196199
3	3	2	9	0.32855556	0.09374581
3	3	3	9	0.34711111	0.12230131
4	1	1	9	0.24388889	0.18996805
4	1	2	9	0.29300000	0.15116382
4	1	3	9	0.29733333	0.16235455
4	2	1	9	0.17455556	0.08383930
4	2	2	9	0.22688889	0.11306795
4	2	3	9	0.17011111	0.09310806
4	3	1	9	0.18455556	0.09429490
4	3	2	9	0.20200000	0.10998750
4	3	3	9	0.17255556	0.08299866
5	1	1	9	0.02328889	0.04945451
5	1	2	9	0.00855556	0.00944869
5	1	3	9	0.01877778	0.02922661
5	2	1	9	0.00584444	0.00486521
5	2	2	9	0.01444444	0.01602429
5	2	3	9	0.01377778	0.01929234
5	3	1	9	0.03266667	0.04534865
5	3	2	9	0.04466667	0.07070537
5	3	3	8	0.02937500	0.04005331

Level of S	Level of T	N	-----DR-----	
			Mean	Std Dev
1	1	45	0.32868667	0.24910757
1	2	45	0.37982222	0.27478027

1	3	45	0.31920000	0.27637800
2	1	45	0.39194000	0.30448815
2	2	45	0.41500000	0.30367132
2	3	45	0.43237778	0.30673599
3	1	45	0.42577778	0.45375463
3	2	45	0.47308889	0.46993751
3	3	44	0.43459091	0.42421788

The GLM Procedure

Level of D	Level of S	Level of T	-----DR----- N	Mean	Std Dev
1	1	1	9	0.61433333	0.19917894
1	1	2	9	0.68933333	0.20791164
1	1	3	9	0.61344444	0.22170482
1	2	1	9	0.71055556	0.25356957
1	2	2	9	0.77311111	0.21067122
1	2	3	9	0.77677778	0.22033768
1	3	1	9	0.94833333	0.60545727
1	3	2	9	0.95711111	0.61839620
1	3	3	9	0.77688889	0.58884812
2	1	1	9	0.45866667	0.13898561
2	1	2	9	0.53377778	0.15017055
2	1	3	9	0.48311111	0.20744906
2	2	1	9	0.53922222	0.26253608
2	2	2	9	0.60044444	0.16171357
2	2	3	9	0.61866667	0.18516817
2	3	1	9	0.63588889	0.34313534
2	3	2	9	0.74433333	0.40926031
2	3	3	9	0.71677778	0.39860751
3	1	1	9	0.34722222	0.13719856
3	1	2	9	0.39600000	0.14183970
3	1	3	9	0.34388889	0.19732805
3	2	1	9	0.44400000	0.19621353
3	2	2	9	0.44733333	0.15541798
3	2	3	9	0.45777778	0.16434398
3	3	1	9	0.36900000	0.09903409
3	3	2	9	0.40855556	0.11602706
3	3	3	9	0.39655556	0.11057589
4	1	1	9	0.20544444	0.15727850
4	1	2	9	0.25900000	0.17592896
4	1	3	9	0.14766667	0.13584366
4	2	1	9	0.24333333	0.12589480
4	2	2	9	0.22500000	0.12999904
4	2	3	9	0.28477778	0.14582162
4	3	1	9	0.15422222	0.10041262
4	3	2	9	0.23788889	0.06476968
4	3	3	9	0.20755556	0.05898116
5	1	1	9	0.01776667	0.04149901
5	1	2	9	0.02100000	0.04922906
5	1	3	9	0.00788889	0.00962347

5	2	1	9	0.02258889	0.04872957
5	2	2	9	0.02911111	0.05767461
5	2	3	9	0.02388889	0.03056732
5	3	1	9	0.02144444	0.02884056
5	3	2	9	0.01755556	0.01899415
5	3	3	8	0.03025000	0.04069661

The GLM Procedure

Level of C	Level of S	Level of T	-----DR----- N	Mean	Std Dev
1	1	1	15	0.46815333	0.31473428
1	1	2	15	0.54200000	0.33516009
1	1	3	15	0.46640000	0.34762948
1	2	1	15	0.56942000	0.35741371
1	2	2	15	0.52620000	0.39722667
1	2	3	15	0.61260000	0.36492970
1	3	1	15	0.65486667	0.69838373
1	3	2	15	0.76740000	0.68897873
1	3	3	15	0.64380000	0.64368417
2	1	1	15	0.23524000	0.18261257
2	1	2	15	0.28940000	0.19863851
2	1	3	15	0.19133333	0.15404066
2	2	1	15	0.38280000	0.26351666
2	2	2	15	0.39553333	0.25877289
2	2	3	15	0.34120000	0.22214706
2	3	1	15	0.31086667	0.20129114
2	3	2	15	0.33520000	0.20864570
2	3	3	15	0.30993333	0.20172168
3	1	1	15	0.28266667	0.17366127
3	1	2	15	0.30806667	0.20749026
3	1	3	15	0.29986667	0.23314798
3	2	1	15	0.22360000	0.17319675
3	2	2	15	0.32326667	0.20591103
3	2	3	15	0.34333333	0.24693396
3	3	1	15	0.31160000	0.18571284
3	3	2	15	0.31666667	0.19093105
3	3	3	14	0.34400000	0.16721888

Level of D	Level of C	Level of S	Level of T	-----DR----- N	Mean	Std Dev
1	1	1	1	3	0.86933333	0.10102640
1	1	1	2	3	0.96100000	0.07715569
1	1	1	3	3	0.86900000	0.15675777
1	1	2	1	3	1.02000000	0.00000000
1	1	2	2	3	1.04400000	0.01216553
1	1	2	3	3	1.06933333	0.02657693
1	1	3	1	3	1.75433333	0.02542309
1	1	3	2	3	1.78066667	0.00901850

1	1	3	3	3	1.23833333	0.95126670
1	2	1	1	3	0.47433333	0.03579572
1	2	1	2	3	0.53766667	0.00680686
1	2	1	3	3	0.41200000	0.05922837
1	2	2	1	3	0.67266667	0.02112660
1	2	2	2	3	0.69800000	0.02816026
1	2	2	3	3	0.62100000	0.01852026

The GLM Procedure

Level of D	Level of C	Level of S	Level of T	-----DR----- N	Mean	Std Dev
1	2	3	1	3	0.54833333	0.00577350
1	2	3	2	3	0.54333333	0.02444040
1	2	3	3	3	0.53833333	0.01258306
1	3	1	1	3	0.49933333	0.02064784
1	3	1	2	3	0.56933333	0.01006645
1	3	1	3	3	0.55933333	0.07284458
1	3	2	1	3	0.43900000	0.01852026
1	3	2	2	3	0.57733333	0.02369247
1	3	2	3	3	0.64000000	0.01732051
1	3	3	1	3	0.54233333	0.06266046
1	3	3	2	3	0.54733333	0.05400309
1	3	3	3	3	0.55400000	0.05121523
2	1	1	1	3	0.62566667	0.08130396
2	1	1	2	3	0.72333333	0.06206717
2	1	1	3	3	0.70600000	0.13926952
2	1	2	1	3	0.77433333	0.03501904
2	1	2	2	3	0.78933333	0.02542309
2	1	2	3	3	0.84933333	0.04291076
2	1	3	1	3	1.03500000	0.32866244
2	1	3	2	3	1.28566667	0.07474178
2	1	3	3	3	1.24566667	0.02713546
2	2	1	1	3	0.35700000	0.08185353
2	2	1	2	3	0.43533333	0.05192623
2	2	1	3	3	0.28166667	0.05707305
2	2	2	1	3	0.61233333	0.07215493
2	2	2	2	3	0.56766667	0.08280298
2	2	2	3	3	0.48166667	0.07751344
2	2	3	1	3	0.44166667	0.06601767
2	2	3	2	3	0.51400000	0.01216553
2	2	3	3	3	0.46066667	0.06812733
2	3	1	1	3	0.39333333	0.01474223
2	3	1	2	3	0.44266667	0.05263396
2	3	1	3	3	0.46166667	0.11579436
2	3	2	1	3	0.23100000	0.18929606
2	3	2	2	3	0.44433333	0.07359574
2	3	2	3	3	0.52500000	0.09041571
2	3	3	1	3	0.43100000	0.01014889
2	3	3	2	3	0.43333333	0.00416333
2	3	3	3	3	0.44400000	0.02424871

3	1	1	1	3	0.50600000	0.07607233
3	1	1	2	3	0.56600000	0.04430576
3	1	1	3	3	0.52666667	0.14011900
3	1	2	1	3	0.65333333	0.14294521
3	1	2	2	3	0.60166667	0.04536886
3	1	2	3	3	0.64733333	0.04611218
3	1	3	1	3	0.42266667	0.14179680
3	1	3	2	3	0.52166667	0.06898067

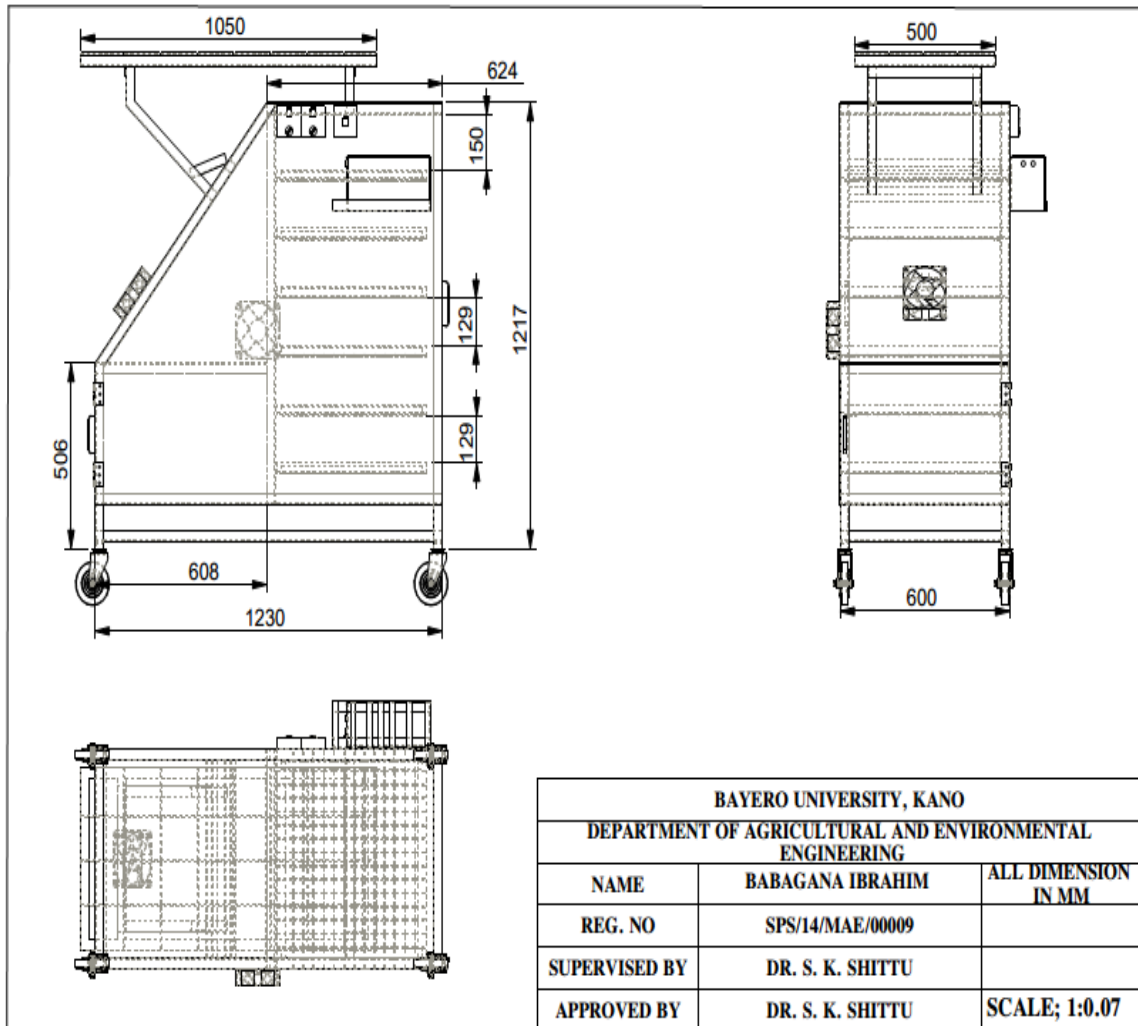
The GLM Procedure

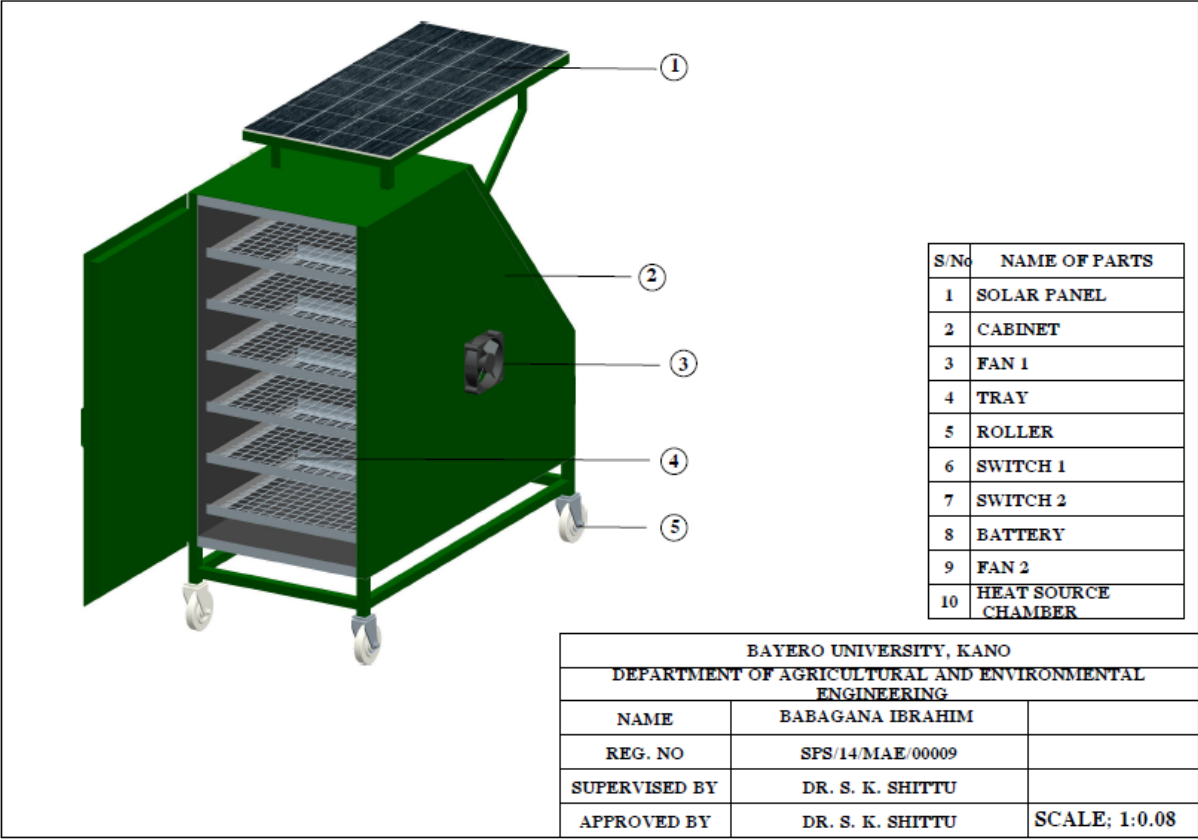
Level of D	Level of C	Level of S	Level of T	-----DR----- N	Mean	Std Dev
3	1	3	3	3	0.51400000	0.06773478
3	2	1	1	3	0.24633333	0.07928640
3	2	1	2	3	0.31000000	0.03968627
3	2	1	3	3	0.17266667	0.04331666
3	2	2	1	3	0.41133333	0.10097690
3	2	2	2	3	0.41800000	0.11818629
3	2	2	3	3	0.35100000	0.08770975
3	2	3	1	3	0.33933333	0.10509678
3	2	3	2	3	0.35266667	0.13579887
3	2	3	3	3	0.34166667	0.10981044
3	3	1	1	3	0.28933333	0.07148660
3	3	1	2	3	0.31200000	0.10912378
3	3	1	3	3	0.33233333	0.19989080
3	3	2	1	3	0.26733333	0.09602777
3	3	2	2	3	0.32233333	0.14190255
3	3	2	3	3	0.37500000	0.13014991
3	3	3	1	3	0.34500000	0.03968627
3	3	3	2	3	0.35133333	0.04314317
3	3	3	3	3	0.33400000	0.03439477
4	1	1	1	3	0.33633333	0.19999083
4	1	1	2	3	0.45400000	0.13387681
4	1	1	3	3	0.22266667	0.20693316
4	1	2	1	3	0.34533333	0.11673189
4	1	2	2	3	0.18833333	0.11172436
4	1	2	3	3	0.45333333	0.05689757
4	1	3	1	3	0.05000000	0.07800000
4	1	3	2	3	0.23666667	0.03036994
4	1	3	3	3	0.21600000	0.06773478
4	2	1	1	3	0.09466667	0.03214550
4	2	1	2	3	0.15800000	0.02151743
4	2	1	3	3	0.08700000	0.04788528
4	2	2	1	3	0.21300000	0.07888599
4	2	2	2	3	0.27666667	0.16928772
4	2	2	3	3	0.23333333	0.10115994
4	2	3	1	3	0.21600000	0.08057915
4	2	3	2	3	0.24600000	0.10311644
4	2	3	3	3	0.19000000	0.07211103
4	3	1	1	3	0.18533333	0.11491011
4	3	1	2	3	0.16500000	0.14080128

4	3	1	3	3	0.13333333	0.12013881
4	3	2	1	3	0.17166667	0.13732565
4	3	2	2	3	0.21000000	0.14177447
4	3	2	3	3	0.16766667	0.06653069
4	3	3	1	3	0.19666667	0.05507571
4	3	3	2	3	0.23100000	0.07108446
4	3	3	3	3	0.21666667	0.05859465
5	1	1	1	3	0.00343333	0.00308923

The GLM Procedure

Level of D	Level of C	Level of S	Level of		-----DR-----	
			T	N	Mean	Std Dev
5	1	1	2	3	0.00566667	0.00321455
5	1	1	3	3	0.00766667	0.00680686
5	1	2	1	3	0.05410000	0.08480407
5	1	2	2	3	0.00766667	0.00808290
5	1	2	3	3	0.04366667	0.04411727
5	1	3	1	3	0.01233333	0.01965536
5	1	3	2	3	0.01233333	0.01569501
5	1	3	3	3	0.00500000	0.00500000
5	2	1	1	3	0.00386667	0.00417892
5	2	1	2	3	0.00600000	0.00346410
5	2	1	3	3	0.00333333	0.00416333
5	2	2	1	3	0.00466667	0.00251661
5	2	2	2	3	0.01733333	0.01703917
5	2	2	3	3	0.01900000	0.02868798
5	2	3	1	3	0.00900000	0.00692820
5	2	3	2	3	0.02000000	0.02364318
5	2	3	3	3	0.01900000	0.02007486
5	3	1	1	3	0.04600000	0.07118989
5	3	1	2	3	0.05133333	0.08718563
5	3	1	3	3	0.01266667	0.01553491
5	3	2	1	3	0.00900000	0.00721110
5	3	2	2	3	0.06233333	0.10196241
5	3	2	3	3	0.00900000	0.00360555
5	3	3	1	3	0.04300000	0.04288356
5	3	3	2	3	0.02033333	0.02400694
5	3	3	3	2	0.08500000	0.0





S/No	NAME OF PARTS
1	SOLAR PANEL
2	CABINET
3	FAN 1
4	TRAY
5	ROLLER
6	SWITCH 1
7	SWITCH 2
8	BATTERY
9	FAN 2
10	HEAT SOURCE CHAMBER

BAYERO UNIVERSITY, KANO DEPARTMENT OF AGRICULTURAL AND ENVIRONMENTAL ENGINEERING		
NAME	BABAGANA IBRAHIM	
REG. NO	SPS/14/MAE/00009	
SUPERVISED BY	DR. S. K. SHITTU	
APPROVED BY	DR. S. K. SHITTU	SCALE: 1:0.08

